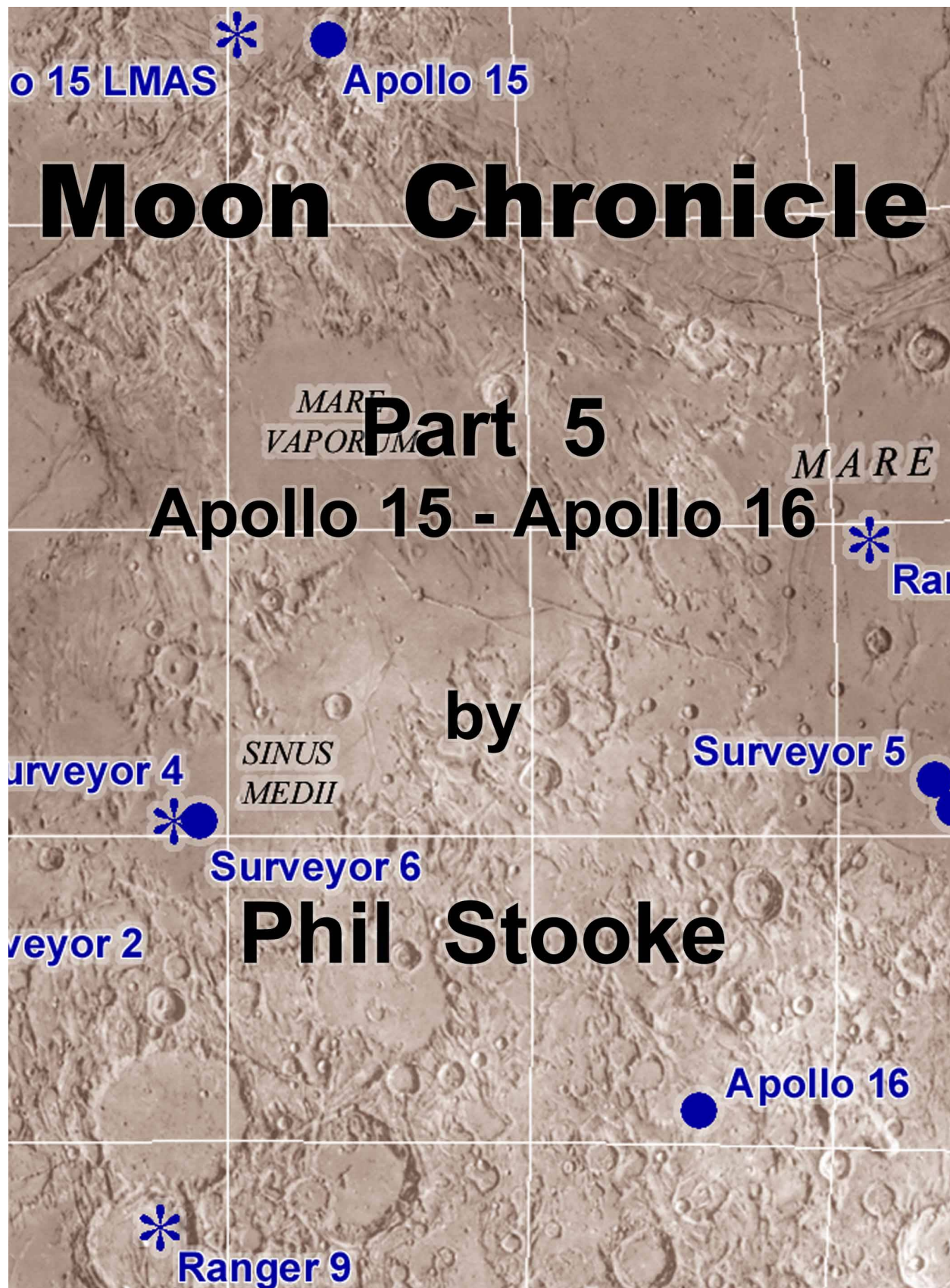




Moon Chronicle

Part 5: Apollo 15 - Apollo 16

by

Phil Stooke

Introduction

The early Apollo missions involved one or two walking EVAs (EVA: Extra-Vehicular Activity) with ranges of about 1000 m from the lander. The last three landings greatly exceeded that. These missions carried an electric Lunar Roving Vehicle (LRV) which could carry astronauts 10 km from the lander on 3 separate excursions. The landing sites were more dramatic and more scientifically interesting. NASA called these 'the great voyages of exploration' with good reason*.

Apollo 11 and 12 had landed in the lunar 'seas' (maria), the dark basalt plains, Apollo 11 in older plains, Apollo 12 in younger plains. Apollo 14 landed in a hilly region composed of ejecta, material thrown out of the Imbrium impact basin as it formed from the impact of a large asteroid. The Apollo 14 material, the Fra Mauro Formation, was older than the dark lava flows of the nearby Apollo 12 site and was overlapped by them.

The landings covered in this volume of the Chronicle, Apollo 15 and 16, went to locations very different from the older sites and each other. Apollo 15 landed on the basalt plains of Palus Putredinis, the 'Marsh of Decay', at the foot of the Apennine Mountains and near Rima Hadley, a winding valley apparently the result of a collapsed lava tube. The crew visited all these features. Apollo 16 landed in the lunar highlands, the only mission to do so. An ancient cratered landscape was partly covered with material thrown out of distant impact basins, but some features were thought to be volcanic in origin. This was a mistake by the planetary geologists who chose the landing site. The origin of the debris layer is now thought to be the Imbrium basin but some material might originate in the older Nectaris basin.

This volume also covers several Soviet missions, two sample return flights (one of them successful) and an orbiter. The Soviet lunar exploration program continued, but at a slowing pace as the chance to upstage Apollo was lost. The Luna 19 orbiter appears to have been testing instruments for use at other planetary destinations and produced only limited scientific results at the Moon.

The missions which reached the Moon during this period are listed in a table and illustrated on a map in an appendix at the end of this volume of the Chronicle.

*Cortright, E. M., 1975. Apollo expeditions to the Moon. NASA SP-350. Washington, D. C.: National Aeronautics and Space Administration.

<https://ntrs.nasa.gov/api/citations/19760005868/downloads/19760005868.pdf>

Spacecraft image credits:

Apollo images: Accessed via the Apollo Lunar Surface Journal (surface Hasselblad images) and <https://data.lroc.im-ldi.com/apollo/browse> (orbital images).

Lunar Reconnaissance Orbiter camera (LROC) data: NASA/GSFC/Arizona State University, and Robinson, M.S., *et. al.* (2010). Lunar Reconnaissance Orbiter Camera (LROC) Instrument Overview, *Space Science Reviews*, v. 150, pp. 81-124. <https://doi.org/10.1007/s11214-010-9634-2>

Lunar Reconnaissance Orbiter Laser Altimeter (LOLA): Smith, D.E., Zuber, M.T., Jackson, G.B. *et al.*, 2010. The Lunar Orbiter Laser Altimeter investigation on the Lunar Reconnaissance Orbiter mission. *Space Science Reviews*, v. 150, pp.209-241. <https://doi.org/10.1007/s11214-009-9512-y>

Lunar QuickMap (<https://quickmap.lroc.im-ldi.com>), developed by NASA, Arizona State University and Applied Coherent Technology Corp.

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26 July 1971: Apollo 15

The original Apollo 15 mission would have resembled Apollo 14, with two walking EVAs, but when two landings were cancelled that mission plan was abandoned and the first of the advanced (J-series) Apollo flights took its place. The J series flights featured many upgrades and advances, notably the inclusion of an electric rover (Lunar Roving Vehicle, LRV), consumables to support three 8 hour EVAs, and a set of instruments and cameras in the Service Module which would collect unprecedented data from orbit.

Apollo 15's crew consisted of Air Force Colonel David R. Scott (Commander, previous flights on Gemini 8 and Apollo 9), Air Force Major Alfred M. Worden (Command Module Pilot) and Air Force Lt.-Colonel James B. Irwin (Lunar Module Pilot). The backup crew was Richard Gordon, Vance Brand, and Harrison Schmitt.

Launch occurred on 26 July at 13:34 UT from Kennedy Space Center Pad 39A, and trans-lunar injection took place at 16:30 UT. The CSM 'Endeavour' separated from the S-IVB and docked with the LM 'Falcon' at 17:07 UT. S-IVB burns at 19:22 UT and 23:34 UT put it on a lunar impact trajectory, and it crashed on 29 July at 20:58 UT (Figures 225, 226). Trajectory corrections were made on 27 July at 18:14 UT and 29 July at 15:05 UT. The Service Module instrument package cover was discarded at 15:40 UT on July 29 and Apollo 15 entered lunar orbit at 20:05 UT.

The orbit was adjusted at 00:13 UT on 30 July, and Falcon separated from Endeavour at 18:13 UT. The LM descent began at 22:04 UT and Falcon landed at 22:16 UT on 30 July at 26.13° N, 3.63° E. Scott and Irwin had three EVA periods on the surface with a total time of 18.6 hours, in which they travelled 27.9 km using a Lunar Roving Vehicle (LRV) for the first time, collected 77.3 kg of lunar samples, took photographs, set up an ALSEP and conducted other experiments. Meanwhile Endeavour conducted photography and other orbital experiments from orbit.

Falcon left the surface at 17:11 UT on 2 August, 66.9 hours after landing. It docked with Endeavour at 19:10 UT and samples and equipment were transferred to the CSM. The LM ascent stage was jettisoned at 01:04 UT on 4 August and struck the lunar surface at 03:04 UT (Figure 249). The CSM modified its orbit and then ejected a small satellite ('Apollo 15 subsatellite' or 'Particles and Fields Subsatellite 1', PFS-1) from its SIM bay at 20:13 UT on 4 August, into a 102.0 by 141.3 km orbit. The trans-earth injection burn was made on the next orbit at 21:23 UT.

On 5 August Worden made the first deep space EVA, leaving the CM for 38.2 minutes to make three tethered excursions to the SIM bay at the back of the SM to retrieve film canisters from the cameras. On its return to Earth on 7 August the CM separated from the SM at 20:18 UT and entered the atmosphere. One of the three large parachutes did not open fully but the spacecraft splashed down safely on 7 August at 20:46 UT after a flight lasting 295.5 hours. Splashdown occurred at 26° 7' N, 158° 8' W, 500 km north of Honolulu, Hawaii and 9.8 km from the USS Okinawa recovery ship. The Apollo 15 CM is now on display at the USAF Museum at Wright-Patterson Air Force Base, Dayton, Ohio.

The Apollo 15 SIVB upper stage was deliberately impacted on the Moon to provide a seismic signal to the Apollo 12 and 14 seismometers (NASA 1971d, 1971e). The target was at 3° 39' S, 7° 34.8' W near the crater Lalande (Figure 225C). Initial reports placed the actual impact at 1° 00' S, 11° 52' W, and subsequent analysis later placed it at 1.51° S, 11.81° W, near the crater Turner. The crater formed by the SIVB was later identified in LRO images (Figure 226) at 1.29° S, 11.82° W. It is 30 m across (Wagner *et al.*, 2017). Figure 225C also shows the target for the Apollo 17 SIVB for future reference.

Details of the mission plans and initial results were presented by MSC (1971a) and NASA (1971a) before launch and by MSC (1971b) and NASA (1972) after the mission. MSC (1971a) illustrated plans for walking EVAs in the event that the LRV failed (Figure 225D). These differ significantly from the options illustrated in Figure 214B. The order of EVAs was changed to reflect the high priority of sample collection at the Apennine Front. Interestingly, the abbreviated Apollo 15 EVAs actually conducted resemble these walking EVAs (except in order) more closely than the planned full LRV routes. Given the northerly offset of the actual landing point, the Apennine Front may not have been within reach of walking astronauts.

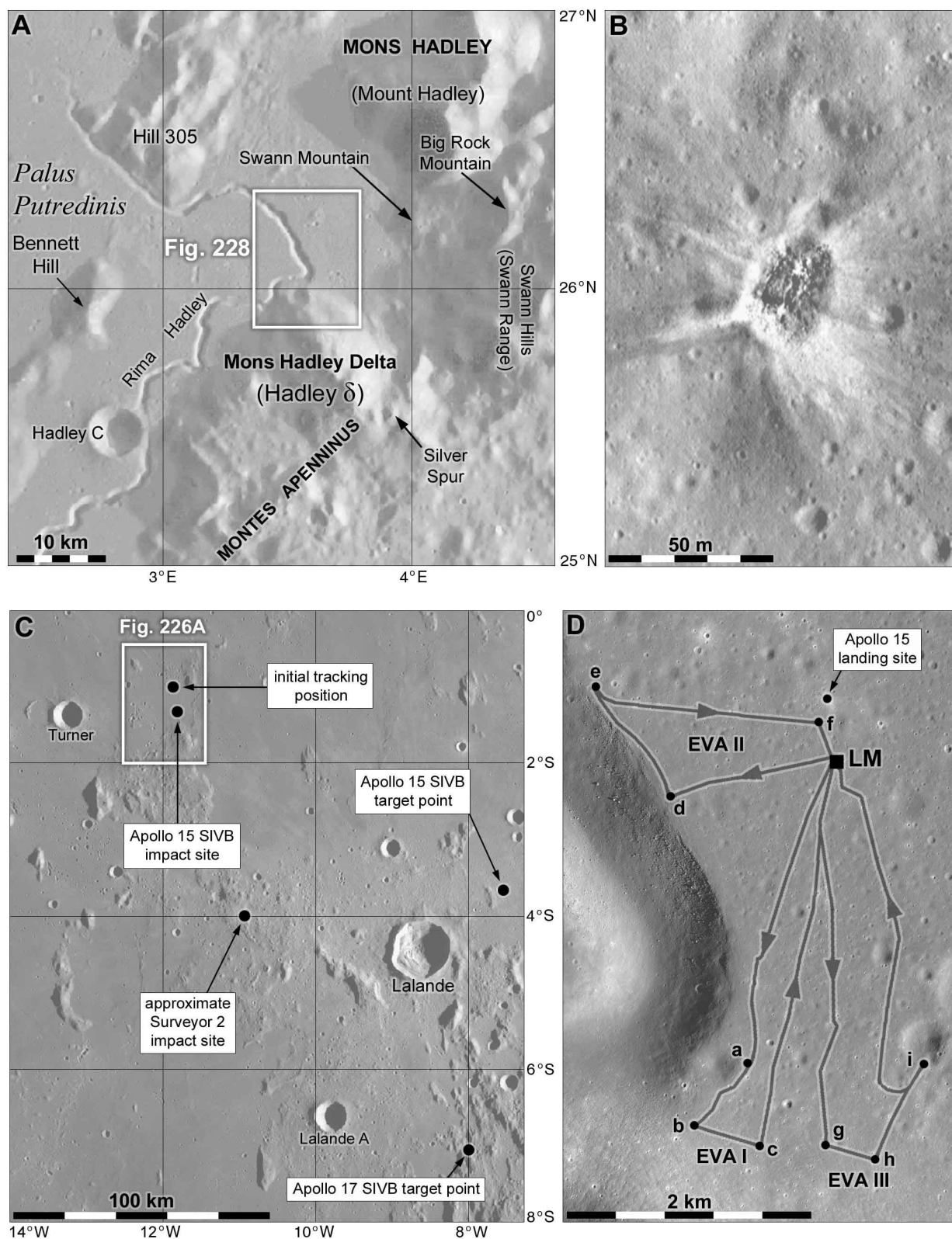


Figure 225. Apollo 15 region and SIVB impact area. A: Apollo 15 region with feature names. B: Apollo 15 SIVB impact crater (LRO image M160030722L). The crater is 30 m across. C: Apollo 15 SIVB target and impact sites. D: walking traverses from MSC (1971).

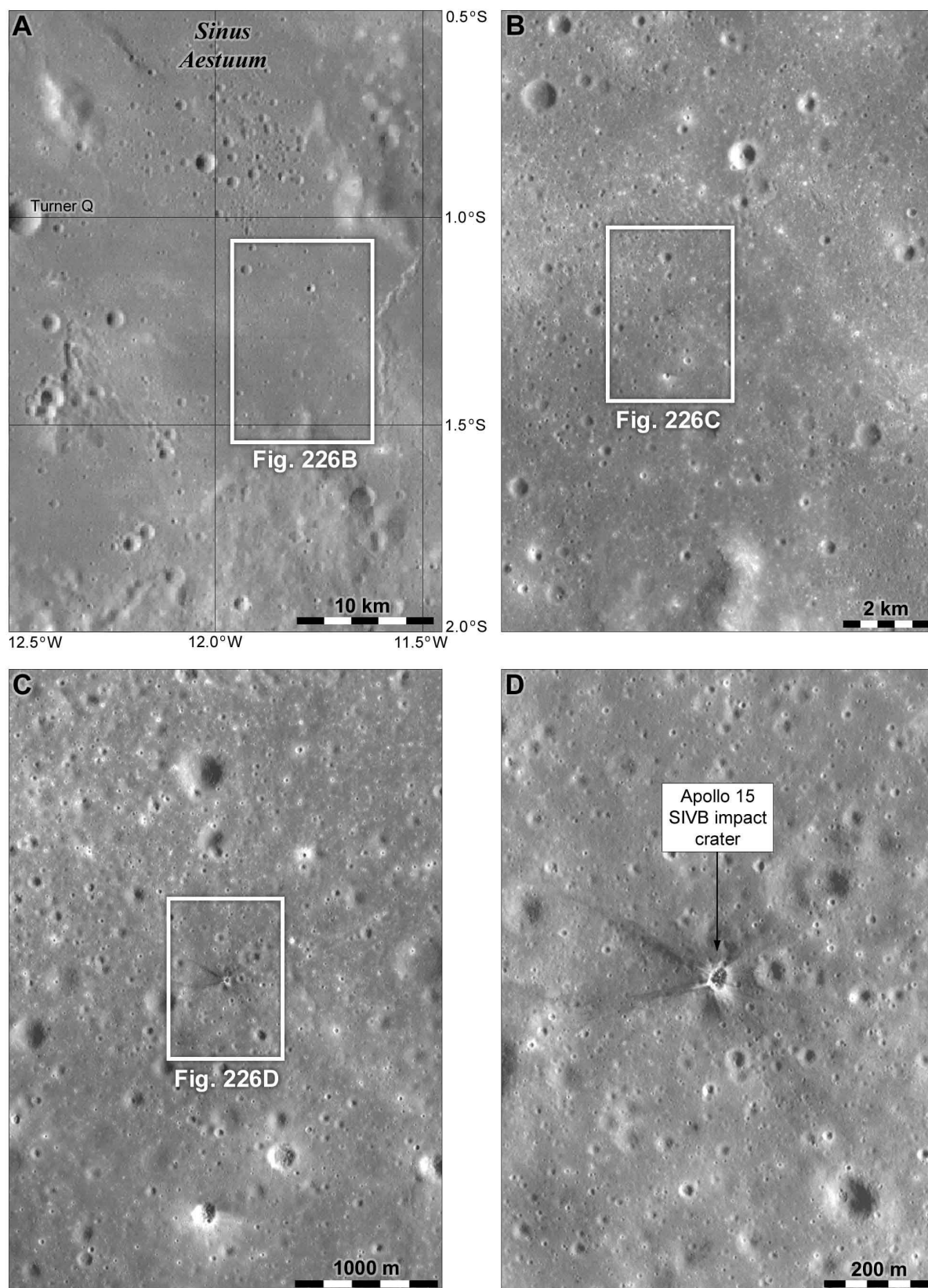


Figure 226. Apollo 15 SIVB impact crater. B, C and D are parts of LRO image M160030722L.

Hadley-Apennine was by far the most spectacular lunar site yet visited. Features were given informal names by future Shuttle astronaut Joe Allen and the Apollo 15 crew (Figures 225A, 227, 228). Lee Silver was a Caltech geologist involved with crew training, Gordon Swann was a USGS geologist and Floyd Bennett was an MSC engineer involved in mission and trajectory planning. Dave Scott, at Microsymposium 55 (just before LPSC in 2014) said that Bennett designed the steeply descending approach path. If they landed near Bennett Hill, his plan didn't work. 'Big Rock Mountain' was named after Rocco Petrone, the Apollo Program Director who had been instrumental in the choice of landing site.

James Head of Bellcomm and Gerald Schaber of USGS Flagstaff are commemorated here, but most names are more whimsical, taken from literature (Durin's Bridge, Rhysling, Earthlight), from their locations (Rim, Elbow) or appearance (Arrowhead). Pluton was also called '750 meter crater'. In early site planning Bridge crater's rim and ejecta were thought to provide a possible route across the rille, though more detailed study suggested this was not feasible. The name Durin's Bridge suggests a similar intended meaning, but it was shown on an Apollo working map (p. 153 in Short, 1975) at the location labelled (DB). I have moved it to a more likely location, assuming an error in the original. The Apollo 15 target point is shown. Matthew, Mark, Luke, Index and Last craters served as guides to the crew during the descent. Salyut commemorates the first Soviet space station, Salyut 1, launched on 19 April 1971. The origin of the name 'Hill 305' is unknown. It could refer to a U. S. military operation (the name was used in France in 1918, and in Korea and Vietnam), or to the approximate azimuth of the hill from the landing site. If the latter is correct it appears to be unique among Apollo feature names.

Scott and Irwin descended in Falcon and landed at 22:16 UT. They touched down harder than any other LM (2 m/second, twice the speed of other landings), causing Irwin to say 'Bam', the first word spoken on the Moon at Hadley, before Scott announced 'Okay, Houston. The Falcon is on the Plain at Hadley.' The name 'The Plain' for the mare surface here is a reference to Scott's time at West Point (The United States Military Academy at West Point, New York), where parades were held on 'The Plain'. They were about 600 m north of their planned landing site, but it took some time to determine this, partly because the landing site was in an area lacking high resolution Lunar Orbiter images.

After quick checks of LM systems the crew were allowed to stay on the Moon. Al Worden, in orbit, told Houston that he could follow events on the radio and see the site during the landing, but did not see the LM land. The astronauts repositioned an antenna to correct for the tilt of the spacecraft, and described their surroundings to Ed Mitchell, the Apollo 14 Lunar Module Pilot, who was their CapCom for the landing. The rolling surface resembled what Mitchell had seen at Fra Mauro rather than the much flatter plains visited by the first two Apollo missions. Scott joked that he had landed in Falcon crater in response to a request from Dick Gordon, the backup Commander, though no crater was actually given that name. As Worden, in orbit, prepared to start operation of the new cameras in the Service Module, the team in Houston was trying to locate the LM. Their initial estimate was that the landing site was nearly 600 m south of the target, though in fact it had landed 600 m north and a little west of the planned location (Figures 232, 233). The uncertainty caused some difficulty in crater identification during the EVAs. President Nixon sent congratulations to the crew via the NASA Administrator, James Fletcher. The LM, now being referred to as Hadley Base, was significantly tilted, and the crew made star sightings out of the windows to establish the attitude. Joe Allen, taking over as CapCom, asked if they saw the rille during the descent, and Scott said yes.

Now the crew attempted something which was not done on any other landed mission, opening the overhead hatch and examining the nearby landscape in all directions to assess rover driving conditions and to locate the landing site. This of all Apollo sites had the least satisfactory pre-mission photographic coverage, and the Stand-up EVA (SEVA) would help overcome the deficiencies in their maps. Apollo 15 landed in a gap between high resolution Lunar Orbiter 5 images, and the medium resolution images were of limited quality. First, Irwin's PLSS was moved from its stowed location between them, and then both astronauts donned helmets and gloves and their suits were connected to LM life support systems. Worden was flying overhead again and reported seeing the LM north of the crater Index through his sextant, though he was probably mistaking Index for Last crater (Figure 232). Shortly after this the crew were told they were east of November crater rather than west of it. This contributed to the continuing landing site confusion.

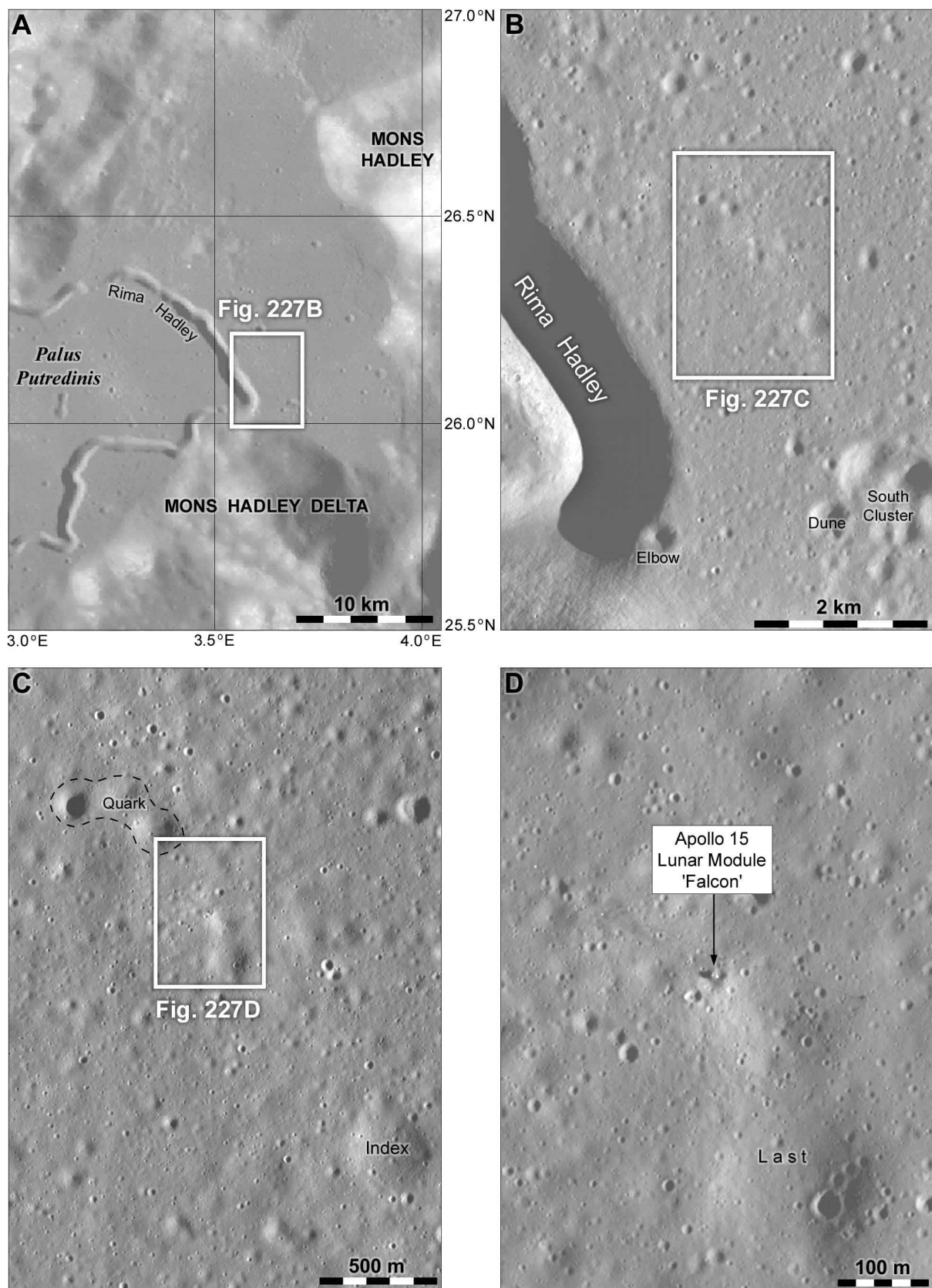


Figure 227. Apollo 15 landing site. B, C and D are parts of LRO image M146959973L.

The LM was depressurized and with Irwin reading instructions, Scott opened the docking hatch which normally provided access between the LM and the Command Module. He climbed up onto the LM ascent engine cover, put his head out through the hatch and took in the view. The LM was on a slight local rise and offered a superb view of the surroundings.

Scott reported azimuths to several features around them to help locate the landing site, but could not identify a nearby feature to help with this. He reported that driving should be easy, and that he could not see the edge of the rille from the LM. Then he took photographs for a monochrome panorama of the surroundings, followed by very detailed images of several targets including the slope of Hadley Delta with a telephoto lens. He said he could see Big Rock Mountain and then he took a second panorama on colour film.

He provided a detailed description of the features around the horizon and near the LM, misidentifying Last crater as Index. He also referred to a feature across the rille as Sallyport West, possibly the crater named in Figure 228 as Uttermost West. 'Sallyport' was a reference to West Point Academy, an entrance passage in that campus. He gave a detailed description of parallel lineaments running across the face of Hadley Delta. Then Scott returned to the LM cabin. The crew repressurized it, and briefly discussed with Houston a problem they had encountered in the LM in lunar orbit which was now apparent again. Water was leaking from somewhere, and Houston concluded it was from condensation in the EVA suit hoses.

Scott and Irwin now prepared for a rest period before the first EVA. They spoke with Joe Allen in Houston about the reason for their tilt, but from inside the LM it was not clear why they were at such an angle. Later, outside the LM, they could see that the rear footpad was in a small crater. They photographed the scene outside the two windows to document the undisturbed site and took off their EVA suits (the first time this was ever done on the Moon) to blow air through the hoses, to dry them before the upcoming EVA. Then it was time for a quick meal and more discussion with Houston about the surroundings and the location of their landing site. They noted a distinctive glass ball which would be collected later. Al Worden was flying over the site and had a brief conversation with the crew on the ground. Then they charged the PLSS units for the EVA, made other preparations, and eventually climbed into their hammocks and had a good sleep.

Falcon landed with its rear pad in a crater, about 60 cm lower than its front pad, but the 10° tilt was within allowable limits. Early in EVA 1 Irwin collected a contingency sample (Figure 230). Other samples were collected at the points labelled on the map. The solar wind collector (SWC) was set up during EVA 1 and retrieved at the end of EVA 3 for return to Earth. The TV camera, initially mounted on the LM facing the ladder on the forward leg, was moved to a tripod west of the LM to view early surface activities. The LRV was deployed from its storage unit in the LM descent stage and set up before being moved to an area north of the LM for testing and loading. The ALSEP equipment was offloaded southwest of the LM and some packing materials were discarded nearby. Three panoramas were taken at the points marked on Figure 230 during EVA 2. The flag was set up at the end of EVA 2. At the end of EVA 3 the rover was parked east of the LM to give live TV coverage of the lunar liftoff for the first time during the Apollo program.

The Apollo 15 ALSEP (Figure 231) was similar to that carried on Apollo 12 with the addition of the Heat Flow Experiment that was lost during Apollo 13 and a separate Laser Ranging Retroreflector (LRRR). All equipment except the LRRR was connected by cables to the Central Station, which provided power and communications. A detector mounted on the Central Station monitored dust accumulation. A Radio-isotope Thermoelectric Generator (RTG) generated electrical power. A Passive Seismic Experiment (seismometer, labeled PSE) monitored 'moonquakes' and impacts. A Solar Wind Spectrometer (SWS) measured the nature of the solar wind and Earth's extended magnetosphere. SIDE (Suprathermal Ion Detector) and CCIG (Cold Cathode Ionization Gauge) were similar to those flown on Apollo 12 and 14. The Heat Flow Experiment had a central electronics box and two probes inserted into drilled holes.

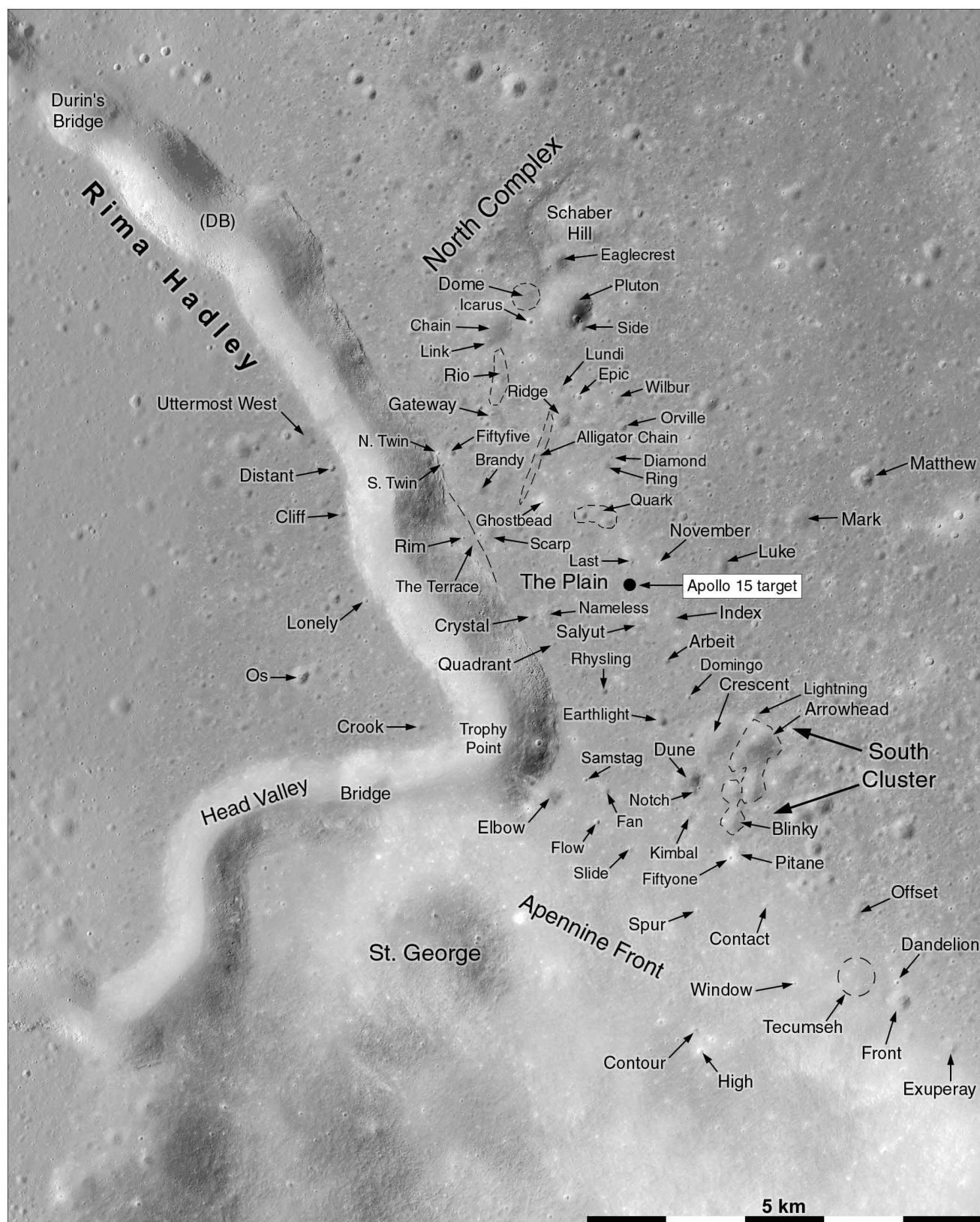


Figure 228: Apollo 15 feature names.

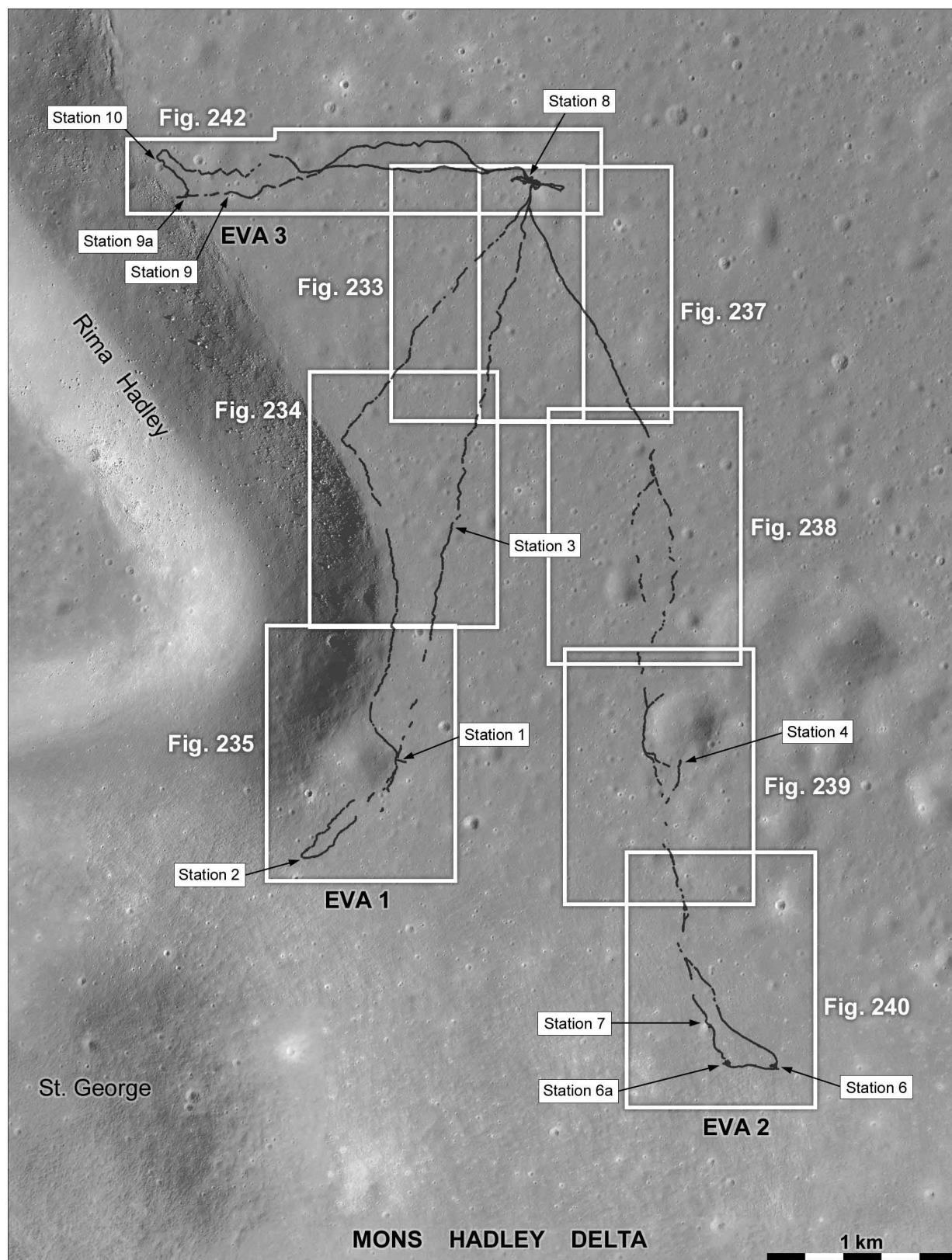


Figure 229. Apollo 15 EVA routes. Black lines show traverses mapped from LRO images. Gaps are areas where no tracks are visible, and mapped tracks are often uncertain. Outlines show the individual EVA map sections.

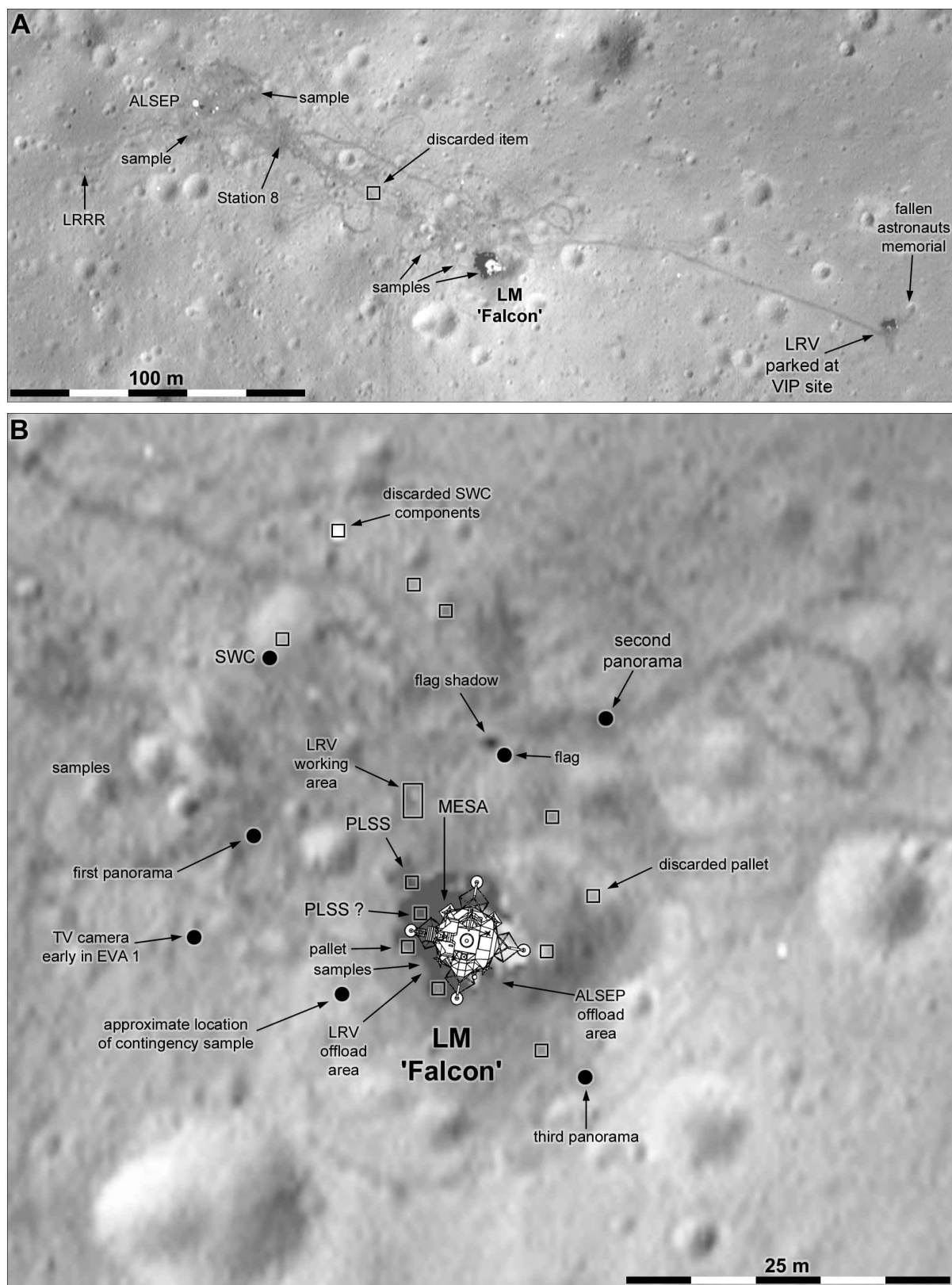


Figure 230. Apollo 15 landing site. A: LM and ALSEP overview. B: LM area.

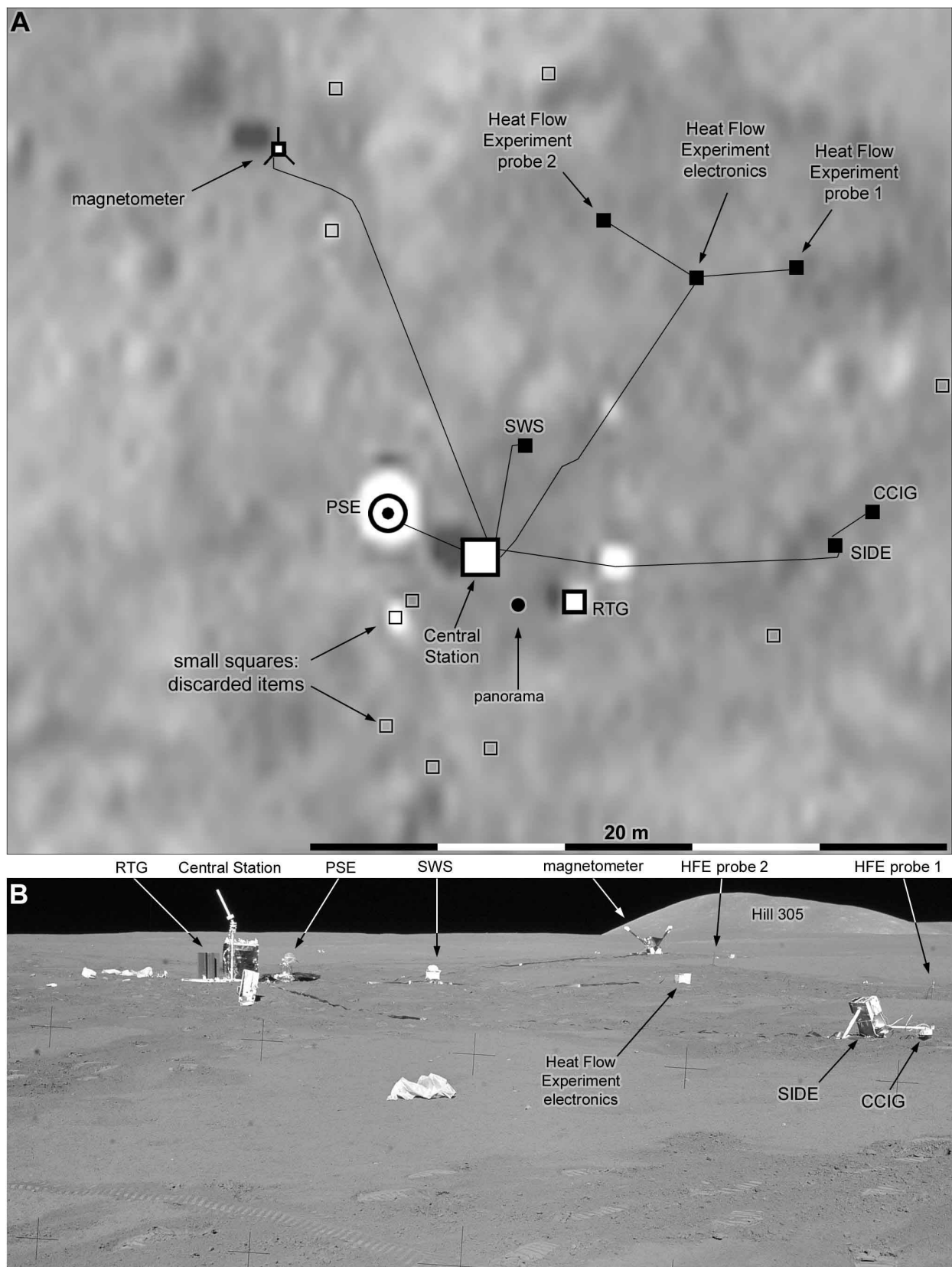


Figure 231. ALSEP area. A: map. B: surface view (part of image AS15-88-11878).

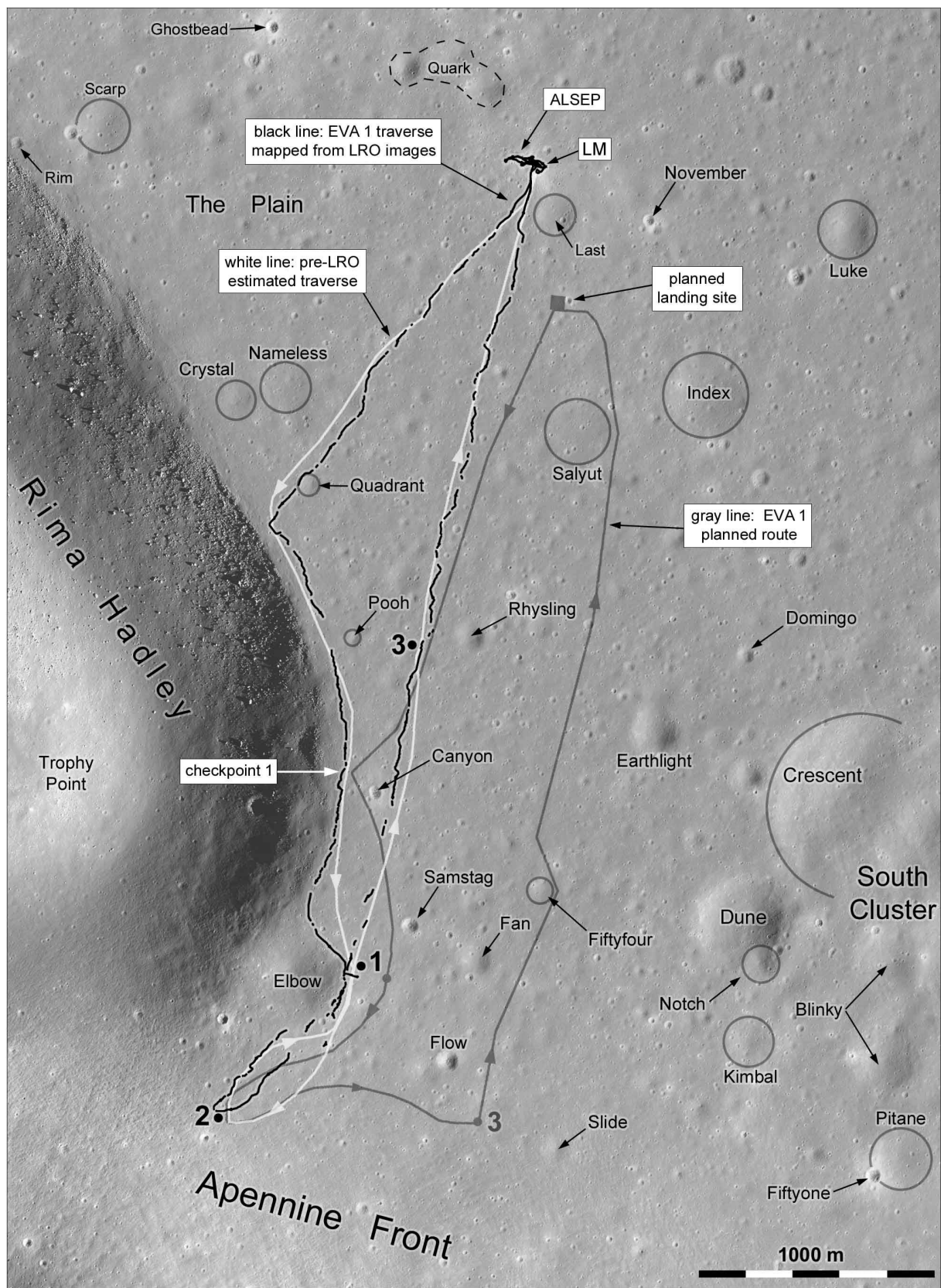


Figure 232: Apollo 15 EVA 1, overview.

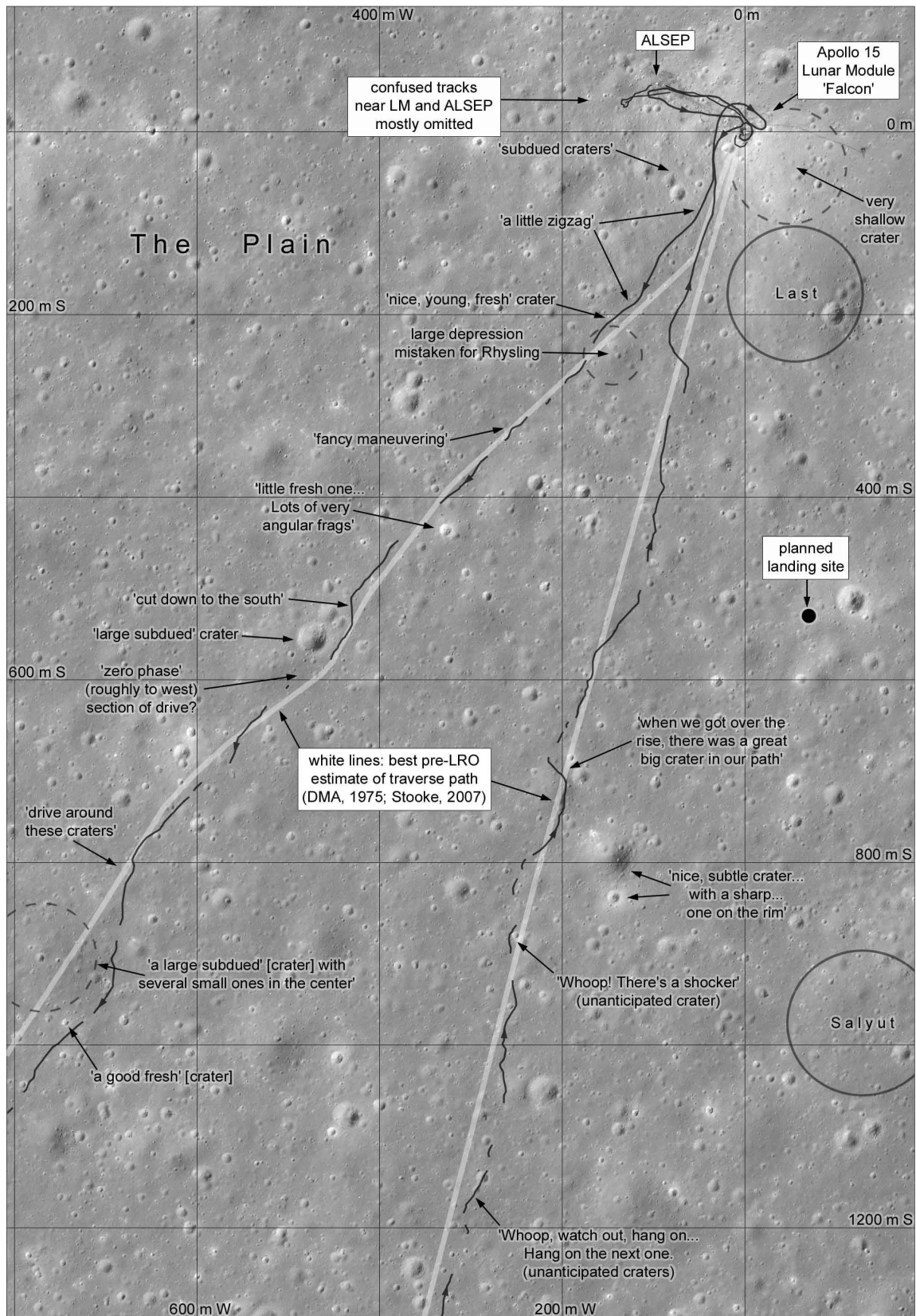


Figure 233. Apollo 15 EVA 1, map 1. Traverses are mapped where tracks are visible.

The first Apollo 15 EVA followed the route shown as a black line in Figures 232-235, mapped by Stooke (2018) using LRO images.. The pre-mission planned route, taken from MSC (1971c), is drawn in grey in Figure 232. The pre-LRO estimate of the traverse is mapped in Figures 233-235, taken from DMA (1975). Rough sketches of the planned EVAs in other Apollo 15 documents and press materials often differed in detail from the official plan. The highest priority for this site was to collect samples from the Apennine Front. This name was applied to the base of the entire west-facing mountain range extending through the Hadley-Apennine region. In this area it corresponds to the mountain Hadley Delta. Total time for EVA 1 was 6.6 hours. The distance covered was 10.3 km, and the greatest distance from the LM was 4 km.

The crew were woken early from their sleep period, after only 5.5 hours, because Houston had observed a drop in pressure in the descent stage oxygen tanks, which provided oxygen to the LM cabin. They could not tell if the leak was from the cabin or the tanks themselves, but if it could not be stopped the mission might have to be cut short. The crew turned off the oxygen feed into the cabin to isolate the two systems and began checking that all valves in the cabin were closed properly. In the process they found that the urine transfer device, which drained urine from the LM cabin into a tank on the descent stage, had been left with its valve open. A cap was in place but it was not entirely leakproof. A few tests showed that this was the cause of the loss of oxygen from the cabin. Then the crew recorded emergency lift-off times during the day in case a sudden departure was necessary and took some time for breakfast.

Houston gave an updated estimate of the landing point, which was then thought to be 250 m south of the actual landing site, and 500 m east of it. The geologists asked for specific samples to be collected, the glass ball near the LM and some black rocks to the west. After exchanging data and instrument readings and discussing plans, the astronauts began dressing for the first EVA. Irwin's PLSS had a small antenna on top which appeared to be damaged, but they did not report it at the time to avoid delaying the EVA. At first it made no difference, and when the antenna broke off later, other systems worked in its place. After numerous system tests and checks they depressurized the LM cabin, and Irwin observed ice crystals through the window, formed from moisture in the cabin air freezing as it vented into the cold LM shadow.

After dealing with problems including the LM hatch not opening fully and straps catching on other objects, Scott backed out of the hatch and pulled a lanyard to open the MESA table on the northwest side of the LM. The TV camera was mounted on the MESA as it had been for the previous missions. Irwin passed out a jettison bag of waste materials and other unwanted items, and Scott threw it down to the south of the ladder. The LEC (Lunar Equipment Conveyor) lanyard was also passed out of the cabin for use later. Jumping off the ladder, Scott looked around and said "Okay, Houston, as I stand out here in the wonders of the unknown at Hadley, I sort of realize there's a fundamental truth to our nature. Man must explore. And this is exploration at its greatest." He moved around the south side of the LM and saw at once why they had landed with such a tilt. The ground was uneven and sloped down into a small crater behind the LM. The LRV was stowed in a folded configuration on the southwest face of the LM and appeared to be in good condition.

Now Irwin attached an equipment transfer bag to the LEC and Scott brought it down to the surface. It contained cameras and other things needed during the EVA. A bag that had held the LEC before deployment fell out of the porch at the same time. Scott noted that he could see Earth high in the lunar sky to the south. Irwin tried to exit the LM but got caught on something and asked Scott for advice. Scott jumped up onto the ladder to see what was happening, and gave advice as Irwin tried again, successfully this time. Scott returned to the surface as Irwin closed the LM hatch and backed down the ladder himself. Scott said he was drawing a circle in the regolith around the large glass ball he had noted before, to protect it until they could collect it, asking Irwin not to pick it up with the contingency sample before it could be photographed. Because the rear footpad was at a low elevation, the front pad below the ladder was barely in contact with the ground and Irwin noted that it moved when stepped on.

Scott deployed the antenna on Irwin's PLSS, taking care as they had already noted that it was damaged. Irwin began collecting a small contingency sample using a special tool with a folding handle, used on all prior Apollo missions but not on the last two. He looked around and said "Oh, boy. It's beautiful out here! Reminds me of Sun Valley", referring to a ski resort in Idaho. Scott took the TV camera off the MESA table and moved it out to a position where, mounted on a tripod, it could view the rover deployment. Irwin prepared a second camera which would film the deployment from the MESA. The TV cable was a trip hazard, as on all earlier missions, and as Scott inspected the LRV, Irwin tried to move the cable to a safer place. Then he put the contingency sample up on the LM porch,

and after Scott had everything ready for rover deployment Irwin pulled a lanyard to release the rover. He climbed down again and took up another lanyard which pulled the rover out from the LM, walking backwards while trying to avoid the TV cable. He fell over but quickly recovered, helped by Scott, and the rover continued to unfold and deploy. Scott was continually worried about his glass ball while all this activity was going on around it.

The rover was still attached to the LM, but should have been free by now, and Houston passed up instructions on how to free it. The astronauts pulled and lifted the front of the rover and successfully freed it, then carried it around to orient it for its first drive. Scott mounted the rover and checked its systems and settings as Irwin moved around to the MESA to collect the 16 mm automatic camera. Its purpose was to record the rover traverses and other activities but it worked very rarely on this mission, resulting in considerable uncertainty in the EVA routes. The most useful film retrieved from this camera covered a drive northwards along the rim of Dune crater in EVA 2. The Apollo 16 version of the camera worked well but it was not used on Apollo 17. The first test drive began as Scott moved to the east along the south side of the LM and then north to loop around it, but he noted that the front steering was not working. Irwin walked behind him trying to film the drive with the 16 mm camera, but found it was not working.

Scott parked the rover north of the MESA on the northwest side of the LM, and moved over to the TV camera to point it at the rover. Irwin mounted the 16 mm camera on the rover, and both astronauts began loading the rover for the first traverse. This included placing the TV camera on the rover, where for the first time on any Apollo landing it could be controlled from Earth while the crew worked nearby. Irwin's PLSS was indicating a problem, but all indications were that it was a sensor malfunction and he was safe to continue the EVA. As they worked at the MESA they discarded unwanted packaging materials off to their right, between the MESA and the LM ladder. Scott took the LRV high gain antenna from the MESA and attached it to a mast on the LRV to support TV transmissions at their traverse stops. Then he removed the TV camera from its tripod, unplugged it from the LM power and placed it on the rover, as Irwin loaded the LRV with equipment needed for the EVA. The high gain antenna was pointed at Earth and TV transmissions began soon after as the LRV loading continued. Maps used to guide the driving were attached to the 16 mm camera mast on the front of the LRV.

Irwin now returned to the LM cabin to change some switch settings and to stow the contingency sample. Scott had to brush dirt off his suit before he climbed the ladder to keep as much as possible of it out of the cabin. Irwin climbed the LM ladder as Scott helped Houston diagnose a problem with the rover, whose front wheels could not be steered. The rear wheels steered properly and could be used alone. Irwin now had trouble entering the LM and Scott had to guide him through the very tight opening. Scott took a box of equipment and supplies from the MESA, and it was pulled up with the lanyard and stowed in the LM. Then he prepared the LRV's navigation system, which used a gyroscope and a wheel rotation counter to estimate the position of the rover during the traverse. The mission support team in Houston had given up on the LRV front steering for the time being and advised it should be turned off. Scott took a bite of a fruit stick mounted in his suit, a source of energy and nourishment during the long EVAs. This and a water bag with a straw helped the astronauts cope with their long work days in the suits, but Irwin found he could not reach his water straw. Later in the EVA he became dehydrated, and this plus a potassium deficiency in the Apollo diet (corrected for later missions) contributed to heart problems during the flight and later in his life.

Irwin rejoined Scott on the surface, and they mounted the LRV and prepared to set out on their first long drive, struggling at first to attach their seat belts properly. This first traverse was to the south (Figure 232), to the most important science target of the mission, the Apennine Front. Samples from the foot of the mountain range were so important that they were collected before the ALSEP was deployed, reversing the sequence used for every other landing. Scott turned the rover sharply to the west to skirt the LM, and then back to the south, avoiding a group of shallow craters. Then he turned to the SSW and headed for Rima Hadley and Elbow crater. The original plan was to drive to the edge of the valley at a place called Checkpoint 1 (Figure 232), and then follow the edge of the valley south to Elbow crater. They were behind on their schedule and Houston suggested they omit Checkpoint 1 and head straight for Elbow, but because their landing position was still uncertain they reached the valley first and followed it to Elbow as originally planned. The same uncertainty caused many misidentifications of craters along the route. Irwin described passing features as Scott concentrated on driving, and crew comments sometimes help locate the route on the traverse maps where tracks are not visible in LRO images.

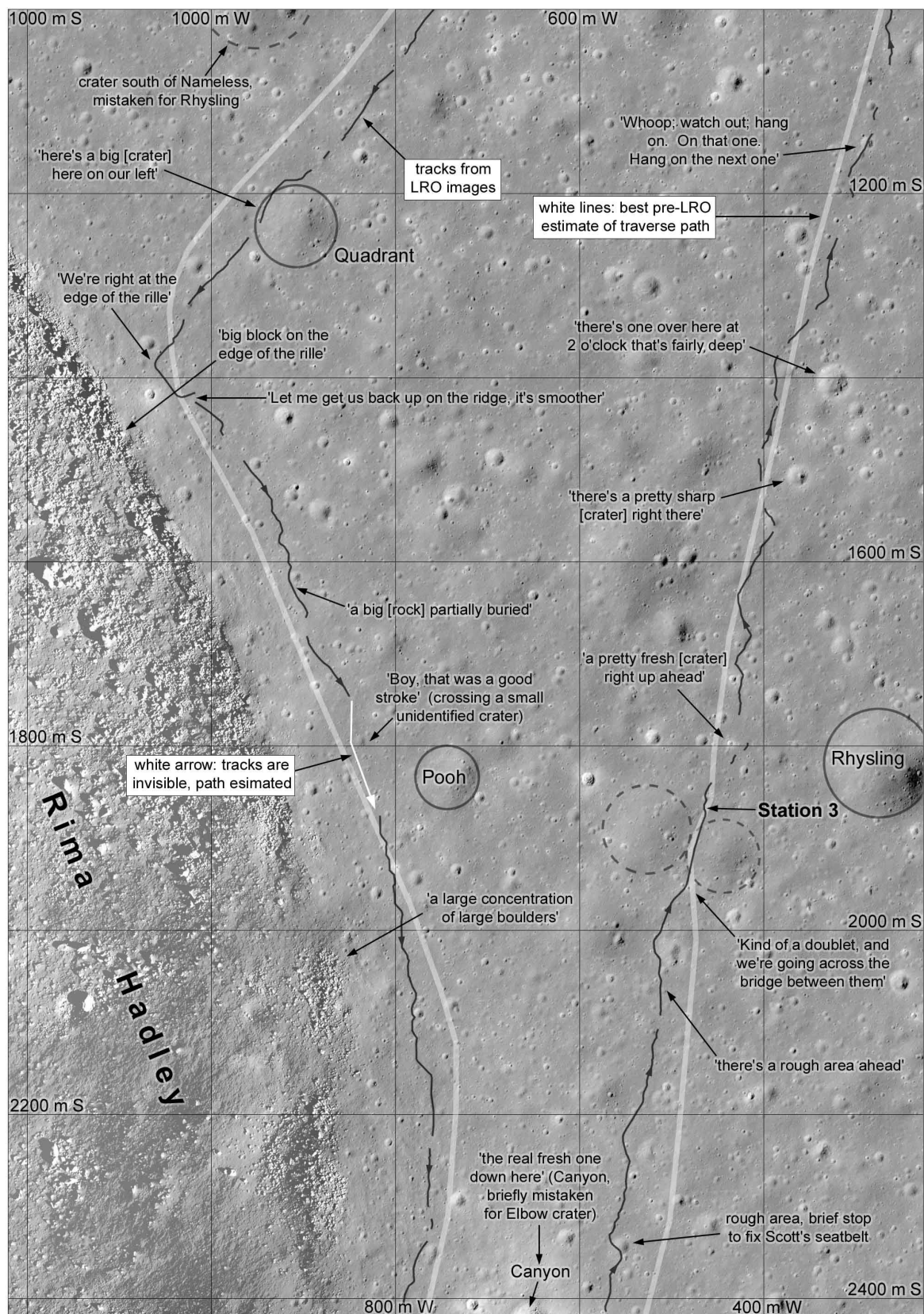


Figure 234. Apollo 15 EVA 1, map 2. White arrows show inferred routes where tracks are not visible.

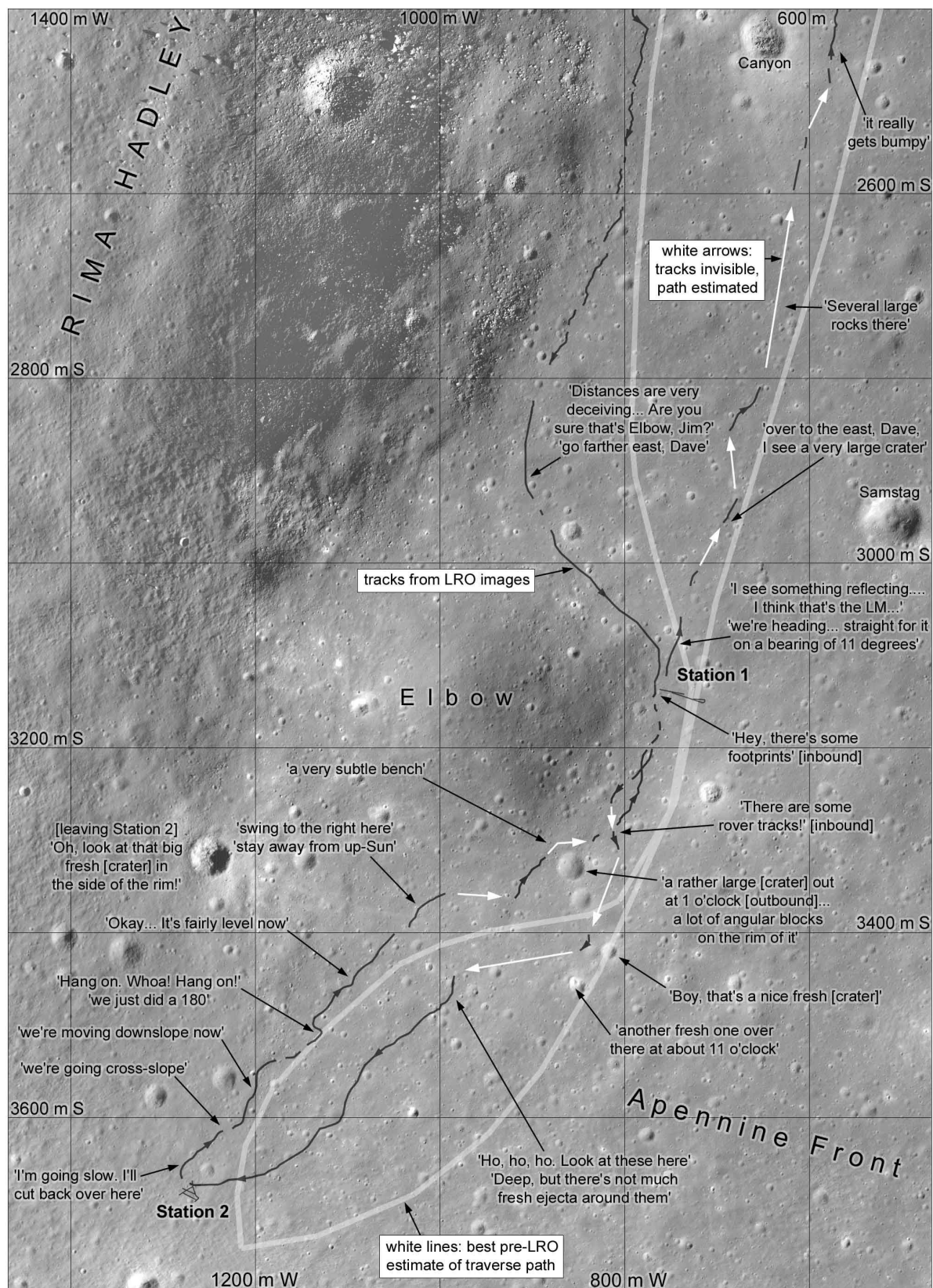


Figure 235. Apollo 15 EVA 1, map 3.

The drive crossed a rolling surface which limited the visibility of the valley edge and many craters until they were very close. As they meandered between craters they occasionally headed nearly to the west, away from the Sun, and Scott noted that visibility decreased markedly when they did. They arrived abruptly at the edge of Rima Hadley, which they usually called Hadley Rille (or just 'the rille'), and turned south, running parallel to the edge of the valley (Figures 232, 234). Elbow was visible from here but the crew found distances difficult to estimate. They usually thought things were closer than they really were. Irwin turned the 16 mm camera on when they reached the rille, but the film did not advance properly and nothing was recorded. As they drove south they described rock clusters along the wall of the rille beside them and looked for layering in the opposite wall, but did not see any obvious layers. Swinging east, they mounted the rounded rim of Elbow and looked for a sampling site. They stopped after a 26 minute drive and pointed the high gain antenna at Earth for the TV transmission. This was Station 1 (Figures 232, 235, 243).

Irwin took a set of images for a panorama to document the site while a communication problem was overcome. Then he and Scott collected several rocks along a line about 50 m long extending radially out from the crater rim. Rocks closer to the rim were expected to come from a greater depth under the original surface. The first was on the poorly-defined rim itself, and the astronauts moved eastwards as they collected two other samples. On returning to the LRV, Scott's boots disturbed regolith around a small crater and he noted it was very white, much brighter than most of the surroundings. This white patch is visible in LRO images (Figure 243). Then they mounted the LRV and drove south towards the mountain. As they began to drive, Joe Allen, the CapCom in Houston, checked with the crew that the 16 mm camera was off. In fact it had not worked at all during the drive.

Scott drove down the eastern rim of Elbow and to the east of several craters just south of Elbow, noting a particularly fresh crater which might make a sampling stop later, though in the end they did not visit it. They turned to the southwest and soon began to climb the lowest part of the slope where geologists had mapped several possible slump or landslide deposits. They could see a prominent 50 m diameter crater up on the rim of St. George and talked about it as a possible sampling site, but it was too far away for them to reach. Then they noted a large boulder not too far ahead and turned west, driving roughly across the slope, to reach it. They stopped and looked around, awed by the spectacular view into Rima Hadley and across the plains to Mons Hadley. This was Station 2 (Figures 232, 235, 243).

Scott and Irwin stepped off the rover and prepared for the station 2 activities, pointing the antenna to Earth for TV transmissions and noting difficulty working in the thick, loose regolith on the slope. Irwin took a panorama of the site, which Scott described as 'The most beautiful thing I've ever seen'. They went to work on the boulder, giving a detailed description of it to the Earthbound geologists. They sampled the fillet, the regolith piled up against one side of the rock, and some nearby regolith, and then used a hammer to take samples from parts of the rock itself. Meanwhile, the TV camera on the rover had observed part of the sampling activities and had then rotated to survey the view, but it had caught on a cable on the rover and could not move. Irwin was asked to return to the LRV to free it. As he did so Scott rolled the boulder over to look at its underside. Irwin collected a sample of the regolith previously hidden under the rock when he returned. Apollo 15 samples from the mountain were about 3.85 billion years old, and the mare plains were 3.3 billion years old.

Then the astronauts moved 10 m east to sample undisturbed regolith with a rake which let them collect small rock chips, though there were not many fragments in the fine, loose regolith here. Next they climbed uphill to take a double core sample on the rim of a small crater (Figure 243). Irwin pushed a core tube into the loose regolith, added the second core tube on top of it and hammered it into the ground. The double core was extracted and stored, and then Irwin photographed a second panorama of the site from near the core sample site. Scott collected a camera with a telephoto lens for high resolution photography, and used it to view the rocky walls and floor of Rima Hadley. This was the first time on an Apollo landing where a telephoto lens was used, prompted by the array of distant features of interest to geologists at this site. The astronauts now mounted the rover and prepared to leave Station 2.

The planned return route (Figure 232) had included a Station 3 at the base of the slope east of Station 2, but as they were running behind schedule this was omitted and they returned directly to the LM. Scott drove the rover down the hill, moving diagonally to lessen the slope. Even so, at one point they lost traction and swung around until they were facing almost in the opposite direction (Figure 235: 'we just did a 180'). Soon they were back on level ground and approaching the south rim of Elbow, where they turned to the east and were facing the Sun. They noted that visibility was better facing towards the Sun than away from it, where a lack of shadows made relief difficult to

interpret. They passed a crater here which they had seen from the east side earlier, noting a shallow bench or ledge between it and Elbow, and then saw their southbound tracks, which they followed back to Station 1. Scott noted the patch of white regolith he had kicked up at Station 1 and now saw that the LM was visible in the distance. They drove straight towards it, seeing a crater east of them which they thought might have been Fiftyfour. This was named after the 'Class of Fiftyfour', students of West Point who graduated with Scott in 1954. Another feature of interest was a distinct horizontal band visible around the base of a spur of Mons Hadley to the northeast.

Scott suddenly stopped the LRV to put his seatbelt on properly. Both astronauts struggled to connect their seatbelts because their EVA suits inflated to a larger size than anticipated on the Moon, and now Scott's had come undone. They moved on and crossed a ridge between two craters, when Scott noted an interesting rock, a vesicular basalt. He decided to collect it and stopped the LRV, repeating the excuse he had just used about his seatbelt to conceal this unplanned sampling stop from the team back in Houston who were eager to start ALSEP deployment as soon as possible. He stepped off and collected the rock, known later as the Seatbelt Basalt, and took pictures for a partial panorama of the site. This unplanned stop is labelled Station 3 in Figures 232 and 234, borrowing the designation from the abandoned site east of Station 2. Moving on, they described the mountains of the Swann Range which they had flown over before landing, and numerous craters along the route which help locate the traverse where tracks are difficult to see. Scott saw many rocks he wished he could pick up, including one sitting on top of a pedestal-like mound of regolith on a crater rim. As they approached the LM they noted Last crater but mistook it for Index as their exact landing site was still unclear to them. They looped around the LM on its north side and parked southeast of it to unload the ALSEP.

Scott freed the TV camera from the cable it had caught on and tried to orient the high gain antenna, but had trouble doing that with the Sun in his eyes. They decided to offload the ALSEP without TV coverage. First they stowed the geology tools on the back of the rover and Irwin opened the ALSEP storage bay doors. They removed the two large packages containing the ALSEP equipment and placed the plutonium fuel rod in the RTG. Scott removed the Heat Flow drill from the equipment bay and put it on Irwin's seat on the LRV, then did the same with the LRRR and closed the equipment bay doors to help keep the LM cool. Irwin picked up the ALSEP 'barbell', the two packages connected by a cross-bar, and carried it around the LM on its northern side and out to the northwest for deployment. Scott drove the LRV out to the ALSEP site as Houston informed him that his oxygen reserve was lower than expected and might cut the EVA short. He found a suitable location for the ALSEP and directed Irwin as he approached with his heavy load and set it down just past the rover. Scott had some difficulty pointing the high gain antenna at Earth but succeeded eventually, and TV transmissions resumed.

Irwin separated the ALSEP packages and connected the RTG cable to the Central Station (CS) as Scott removed the LRRR from the rover seat. He placed it on the ground, ready to deploy later. Irwin removed the Heat Flow Experiment (HFE) equipment from the ALSEP package, and Scott moved it to its deployment site 10 m further north. He connected the parts of the HFE and laid them out on the ground (Figure 231), as Irwin set out the SIDE instrument and connected it to the Central Station, nearly falling over in the process. The connectors on the CS were at the bottom, and to facilitate making the connections Irwin had put the CS down on its side with the connectors at the top. Now he tipped it back to its upright position. Then he set out the base of the seismometer, jumping to compress the regolith at the site first, as Scott continued working with the HFE. Two packaging items from the HFE were no longer needed so Scott threw them aside, demonstrating his lunar sporting abilities for the TV. He lost his balance and stumbled but quickly recovered. As Irwin deployed the seismometer and its thermal skirt Scott picked up and tested the drill. Joe Allen in Houston advised him not to throw it.

Scott prepared to drill the first HFE hole, northeast of the deployed instrument unit, as Irwin set out the solar wind spectrometer and the magnetometer. The drill would insert a three-section stem into the ground to a depth of 3 m, and the first section went in easily, but Scott soon experienced considerable resistance to further drilling. Eventually the second stem was emplaced and Scott released the drill, before helping Irwin change to an auxiliary water supply in his PLSS on instructions from Houston. Now a third stem was added to the part in the ground, and with great effort the drill drove it until about half of it was buried, giving a full depth of about 1.6 m. He tried the drill again without making any progress and gave up, and now found he could not remove the drill from the stem. Irwin, meanwhile, had set up the magnetometer. Scott was advised to use a vise to grip the stem as he twisted the drill, and it successfully freed the drill. Now Scott had to switch to his auxiliary water supply, while Irwin encountered another problem. A sunshade on top of the CS would not deploy properly, and he had to drop to his knees to fix it, then get back up which was not easy in the EVA suit. Scott similarly had some difficulty picking up a dropped probe for the

HFE but succeeded eventually. He placed the probe in the drill stem and pushed it down with a rod, then moved to the position for the second drill hole.

The second drill followed the pattern of the first, going in easily to the top of the first section and with more difficulty after that. When both of the drill stem sections were in place Scott needed to use the vise again to remove the drill. It was still attached to the first stem and he had trouble removing it, taking so long that the task had to be abandoned for the time being. Irwin was still working on the CS and its antenna. The astronauts were warned they only had a short time left in the EVA and Joe Allen, in Houston, asked Scott to deploy the LRRR instead of continuing with the heat flow work. Scott left the second probe on the equipment rack used during HFE deployment and returned to the rover to collect the LRRR. He carried it out to the southwest far enough, he hoped, to avoid its reflectors being affected by dust or exhaust during the LM takeoff. Irwin finished pointing the CS antenna, and then turned to deploying the SIDE and CCGE. These instruments had caused trouble on the last two missions but had been redesigned and were easier to deploy this time. Scott put the LRRR in a suitable location and pointed it to Earth before backing away very carefully to avoid kicking dust onto it. It was important to keep its reflectors as clean as possible. This reflector was larger than those used at the Apollo 11 and 14 sites and gave a better signal. It has been used ever since, including on 22 January 2018 when China made its first lunar laser reflector detection from the Yunnan Astronomical Observatory in Kunming, southern China, showing that it had not accumulated a significant layer of dust.

On returning to the ALSEP Scott was asked to turn the drill to a position which would stop it overheating, and then he took pictures to document the ALSEP configuration. The two astronauts boarded the LRV and quickly returned to the LM to end the EVA, saving time by leaving their seatbelts undone. They parked north of the MESA, backing up to position it properly, and powered the rover down for the pause between EVAs. Now they unloaded samples and equipment, and Scott took pictures of the LM and rover. The rover was prepared for the break between EVAs by opening battery covers to shade heat radiators, to prevent overheating. Irwin climbed back into the LM, taking a sample box with him, and Scott climbed up to hand him the Seatbelt Basalt sample, still unknown to Houston. Then he returned to the surface and set up the Solar Wind Collector (SWC), identical to the foil sheets deployed on the previous Apollo landings. Irwin was supposed to do this earlier, and now Scott was asked to do it though he had not trained for it since his time on the Apollo 12 backup crew, two years earlier. Irwin talked him through the job. Then Scott picked up a glass-coated rock near the SWC site, returned to the LM and climbed up the ladder carrying an equipment bag full of film magazines and other items.

The crew had some difficulty working in the cramped LM cabin, and their fingers were now very sore, but soon they were able to pressurize the cabin and remove their helmets and gloves. They immediately noticed the smell of the lunar dust, which they likened to gunpowder, and were concerned that everything was so dirty. The amount of dust was a concern, prompting them to pull unused jettison bags over their still-suited legs, which seemed to help control the dirt. This had been anticipated and pre-planned, and the procedure was also used by the two later crews. They recharged the oxygen in the two PLSS units and spoke to the head of Flight Crew Operations, Deke Slayton, who told them to take the rest of the day off. Later they spoke to Al Worden as he flew over in the Command Module. He could see the LM in a small sighting telescope, but not the rover tracks. They organized and stowed samples and had a meal, and then conducted a short debriefing with Joe Allen in Houston, who relayed questions about the ALSEP, the LRV and geological observations. The team on the ground had now decided, correctly, that the landing had occurred just north of Last crater. A water leak had been noted in the LM, but was not serious enough to compromise the rest of the mission. Finally the discussion ended and the crew settled down to sleep in the cramped cabin.

The crew were woken after a 7 hour sleep period to find a cabin relatively free of dust, some of which had been caught in a filter as air circulated. Water had leaked from a broken filter before the sleep period, and the crew were asked to look for a puddle where the tilted LM would send it, behind the ascent engine cover. They found it and followed instructions to scoop it up and store it in a container for jettison later. It could not be allowed to remain or sublime away when the hatch was opened because it might interfere with other systems. They were given times for potential emergency liftoffs if they should be required, and instructions to tape a cable on the LRV to prevent the TV camera catching on it.

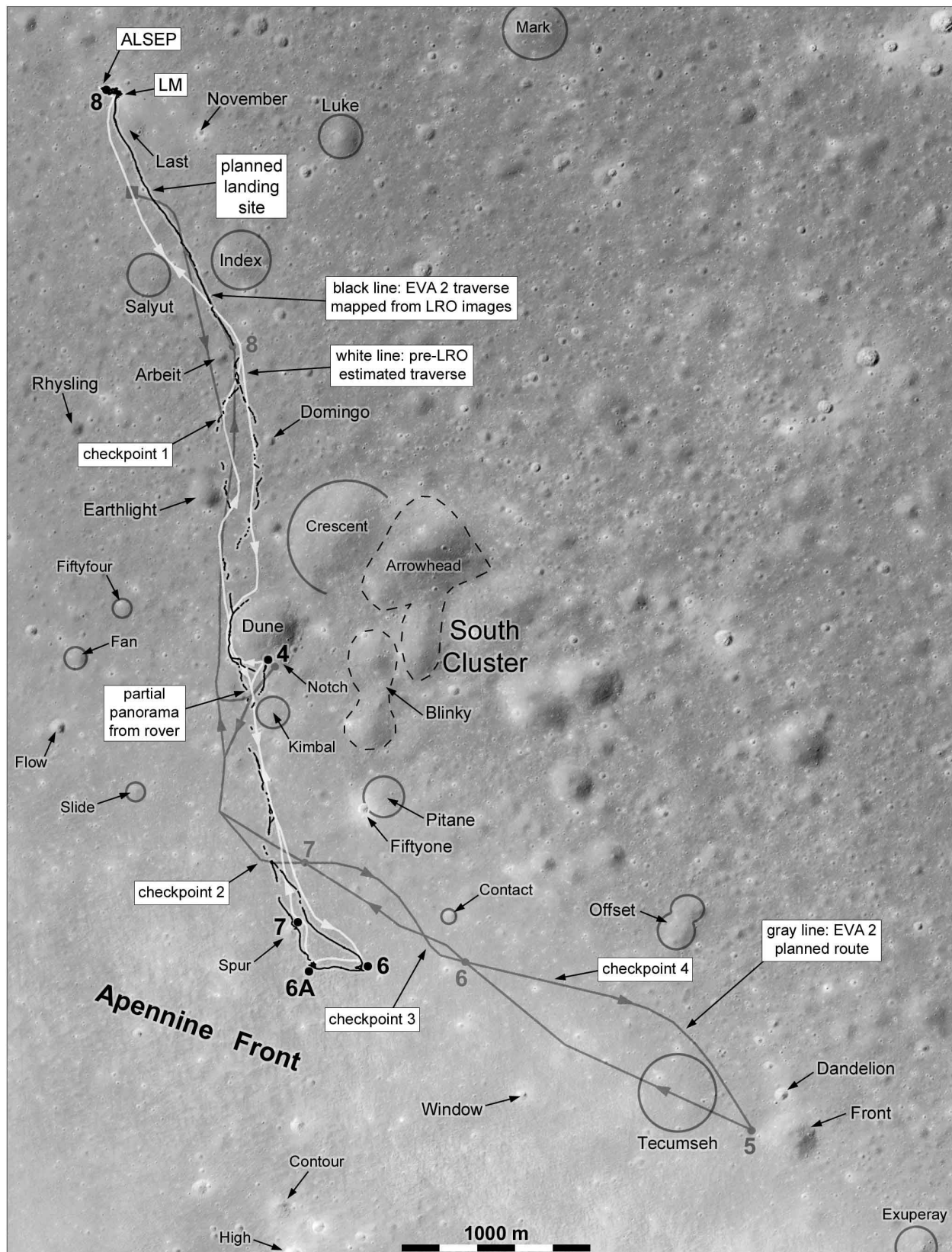


Figure 236. Apollo 15 EVA 2, overview.

The ground team had modified the EVA 2 plan, so this was presented to the astronauts. More oxygen had been used than anticipated on EVA 1 so EVA 2 was shortened by dropping the most easterly stop, Station 5 (Figure 236). A stop at the secondary craters of South Cluster (thought to be created by ejecta from the craters Aristillus or Autolycus to the north of the landing site) was omitted on the drive south to the mountain and would be added back in if time permitted on the return journey (Station 4). The heat flow drill work would be tackled again at the end of the EVA, and a planned stop near Arbeit crater (Station 8, Figure 236) would be moved close to the LM so Irwin could do that while Scott worked on the drill.

Figure 236 shows the EVA 2 route and activities. The background image is a mosaic of LRO images. The planned EVA is taken from MSC (1971c). The pre-LRO estimated EVA route is from Stooke (2007), modified from a map by Ken Rattee in the Apollo Lunar Surface Journal. The DMA (1975) map used as a source for the pre-LRO estimated EVAs 1 and 3 shows an inaccurate representation of EVA 2. It is portrayed in the detailed map sections in Figure 237-240.

Scott and Irwin donned their suits and prepared to exit the LM for EVA 2. One problem had to be dealt with before the EVA, an apparent bubble in the water system in Irwin's PLSS. The PLSS was recharged to clear it. Scott's heart rate sensor was not working properly and Scott was advised to pay attention to his heart rate during the EVA. Irwin's suit had a broken communication antenna, but it worked when taped together. After many other checks and preparations they opened the hatch and started the EVA. The hatch opened wider now than it had the previous day, making exit easier. Scott climbed out first, stopping on the top step of the ladder to deal with the jettison bag and other items to be thrown out, including the mopped-up water. These were dropped south of the ladder. Then Scott took an equipment transfer bag containing cameras and other items with him down the ladder, collected a package of food and other items from the MESA and carried it up the ladder to stow in the cabin for later use. Scott taped a cable on the rover as instructed to prevent the TV camera catching on it.

Irwin joined Scott on the surface and they prepared the LRV for its traverse to the Apennine Front, loading equipment and checking its systems. Scott picked up the glass sphere he had noted early in EVA 1 and placed it in a sample bag. He called it an Aggie, taking the name from a children's marble made of agate rather than glass. Then he drove the rover a short distance to initialize the navigation system as Irwin photographed him. The pictures taken here showed the EVA 1 tracks out to the ALSEP, allowing them to be separated from the mass of tracks visible in LRO images. Instructed from Houston, Scott flipped a circuit breaker and the front steering became operational. The navigation system was set up and the drive south began, taking them past Last crater and then between Index and Salyut on the way to the mountain. Scott soon found it easier to drive with only the front steering engaged, but not long after that he stopped near Index to re-engage the rear steering, finding the best arrangement by experience. As they approached the rim of Crescent crater, part of the South Cluster of secondary craters, Joe Allen passed on a suggestion from Houston that they start the 16 mm camera to record the drive. They did so, but saw later that it was still not working. They had striking views into Crescent and Dune craters, and when they reached Dune's northern rim they turned to the west and then southwards to skirt it. They followed the rim south past the originally planned Station 4 on Dune's southern rim which would now be visited on the return journey.

Many features of geological interest were noted all along this drive. Just north of Dune they spotted a crater about 4 m across, possibly elongated, with a large rock on its southern side. It might have been a secondary crater. As they looked up at the slopes of Hadley Delta they noted that the few visible craters on the slope (from Spur to Contour and High) seemed to be aligned as if they too were secondaries. Scott stopped driving to take a short rest southeast of Dune, and Irwin took several images for a partial panorama of the site from which an exact location can be derived. He drew attention to a large block on the mountain slope, possibly the one they later examined at Station 6a. Allen reminded them that the next sampling stop should be at a crater which had penetrated the regolith and ejected blocks of the mountain bedrock. They were free to choose any crater which provided suitable blocks. Soon after they resumed driving they passed out of a debris-covered region near South Cluster and entered a distinctly smoother area leading to the foot of the mountain. A shallow trough appeared to run across the base of the slope, and then they began to climb, turning slightly to the left (east) to mount the slope diagonally.

A very large block could be seen near Front crater now, estimated at the time to be perhaps 15 m across. It was too far away, and they decided to stop near Spur crater which they identified without difficulty. They briefly drove towards the Sun before stopping in an area of scattered blocks not obviously associated with any crater. This was Station 6. (Figure 243). They had parked on a slope of about 10 degrees and found working in the soft regolith on

the slope difficult, but the view was spectacular, and they particularly noted fine parallel lineations on the sunlit west-facing slope of Mons Hadley which had been in shadow during EVA 1. These later turned out to be an illusion caused by small local shadows and illumination just grazing the surface. Scott was impressed by the rover's capabilities, effortlessly climbing this slope and allowing the crew to arrive fresh and ready to work. He aligned the antenna for the TV while Irwin took a panorama nearby, struggling and ultimately failing to point his chest-mounted camera up to the top of the mountain. Scott also brushed dust off the TV camera lens and described a very bright crater northwest of the LM which might have been Ghostbead (Figures 228, 241).

The first sampling stop was a small fresh crater upslope from the rover. They collected glass from the bottom of the crater, regolith from its rim and some nearby rock fragments, and then moved around the rover collecting fragments as they found them. They described each rock to the geologists listening in Houston as they collected it. Irwin took a second panorama from a position west of the first. Allen asked if a rake sample might be useful here and Scott replied that it would not. Then they moved downhill to the north rim of a 10 m crater which offered another sampling location. Irwin noted that Scott had kicked up some white material from below the surface, and they decided to examine it with a trench and a core. Scott broke a large rock with his hammer to expose its interior, and they collected fragments of the rock.

The astronauts moved to the south side of the crater and Irwin dug a trench through the rim with a scoop. The regolith was very fine and easy to dig through, but did not show any obvious layering. Scott, standing in the crater below the trench, fell over as he maneuvered on the very loose surface, and Irwin reached out to help him stand up again. They collected a sample from the trench and placed it in a vacuum-sealed Special Environmental Sample Container on instructions from Houston. As the trench did not excavate the white material seen earlier, they decided to take the core on the north rim of the crater where it was first seen. The core tubes were designed to be stacked on top of each other to allow double depth coring, so the lower tube sections had a hardened base to assist penetration in cohesive regolith and the upper tubes did not. They were running out of lower core tubes and the regolith was soft here, so they were instructed to use only an upper tube now. The coring was easily accomplished, and then they returned to the rover.

At the LRV they noted that the wheel tracks were very shallow while their bootprints were deep in the soft regolith on a crater rim, because the wheels spread weight over a larger area. Irwin walked beside the wheel tracks and Scott photographed the two sets of tracks for the soil mechanics scientists. They collected a regolith sample near the rover and brushed dust off the vehicle where it was accumulating and absorbing heat. Scott now used the camera with the 500 mm telephoto lens to take pictures of Mons Hadley with its apparent layering, North Complex and other targets including the LM. They put a new film magazine in the 16 mm automatic camera (DAC) to see if it would work better, but at first it appeared to make no difference.

Then they mounted the rover to drive to a large block on the mountain, 300 m to the west, though Scott had to dismount again to turn the TV camera off. Another change in settings on the DAC now seemed to free the film, and a short sequence was successfully recorded near Spur. They drove to the west, keeping at about the same elevation, and noted in passing a small, very bright crater. The slope was steep here, about 15 degrees, and Irwin, sitting on the downslope side, felt rather unsafe. As soon as they stopped above the large block he climbed off the rover, and Scott briefly dismounted. He thought the TV should not be used here because the slope made pointing the antenna difficult, but he was asked to try it anyway. Irwin described a small rock which had rolled down the slope on a curving path, leaving a noticeable track, but did not get a photograph of it, though he did take a panorama from this high point before descending to the block. To avoid the astronauts having to climb back up to the rover after sampling the block, Scott now backed up the rover and drove down to a position just below the block (Figure 243).

When the astronauts approached the large block they noted a distinctly green colour caused by magnesium oxide in the rock, and green grains in the regolith as well. They took a few samples but the site was not regarded as very important and they soon departed for Spur crater. Scott climbed on the sloping rover's upper side easily, but Irwin's seat was harder to get to, so Scott moved a short distance to a better place and Irwin climbed on. He held on to the rover structure for this drive rather than trying to do up his seatbelt, and they drove slowly over to Spur, 200 m to the north (Figures 240, 244).

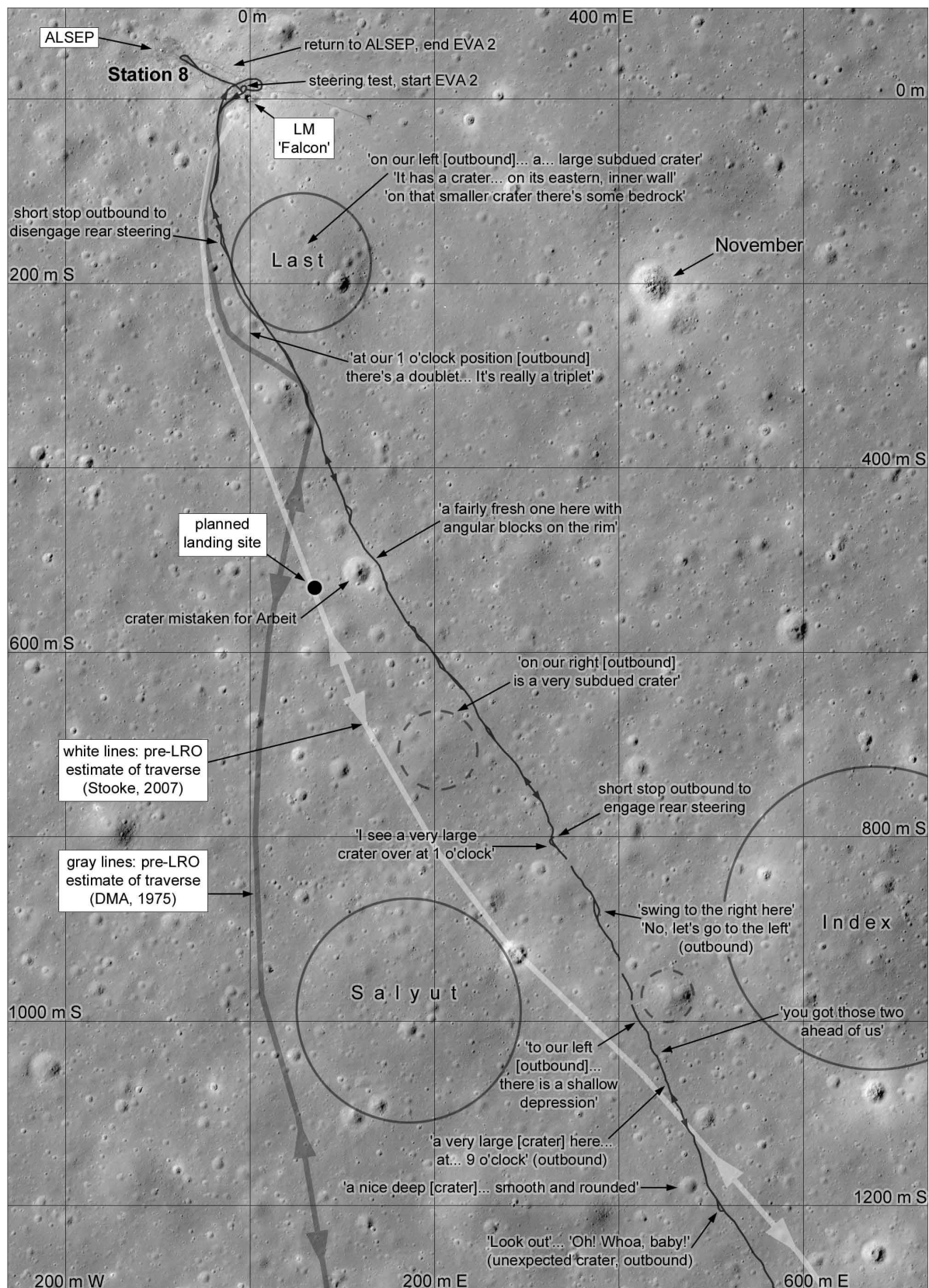


Figure 237. Apollo 15 EVA 2, map 1.

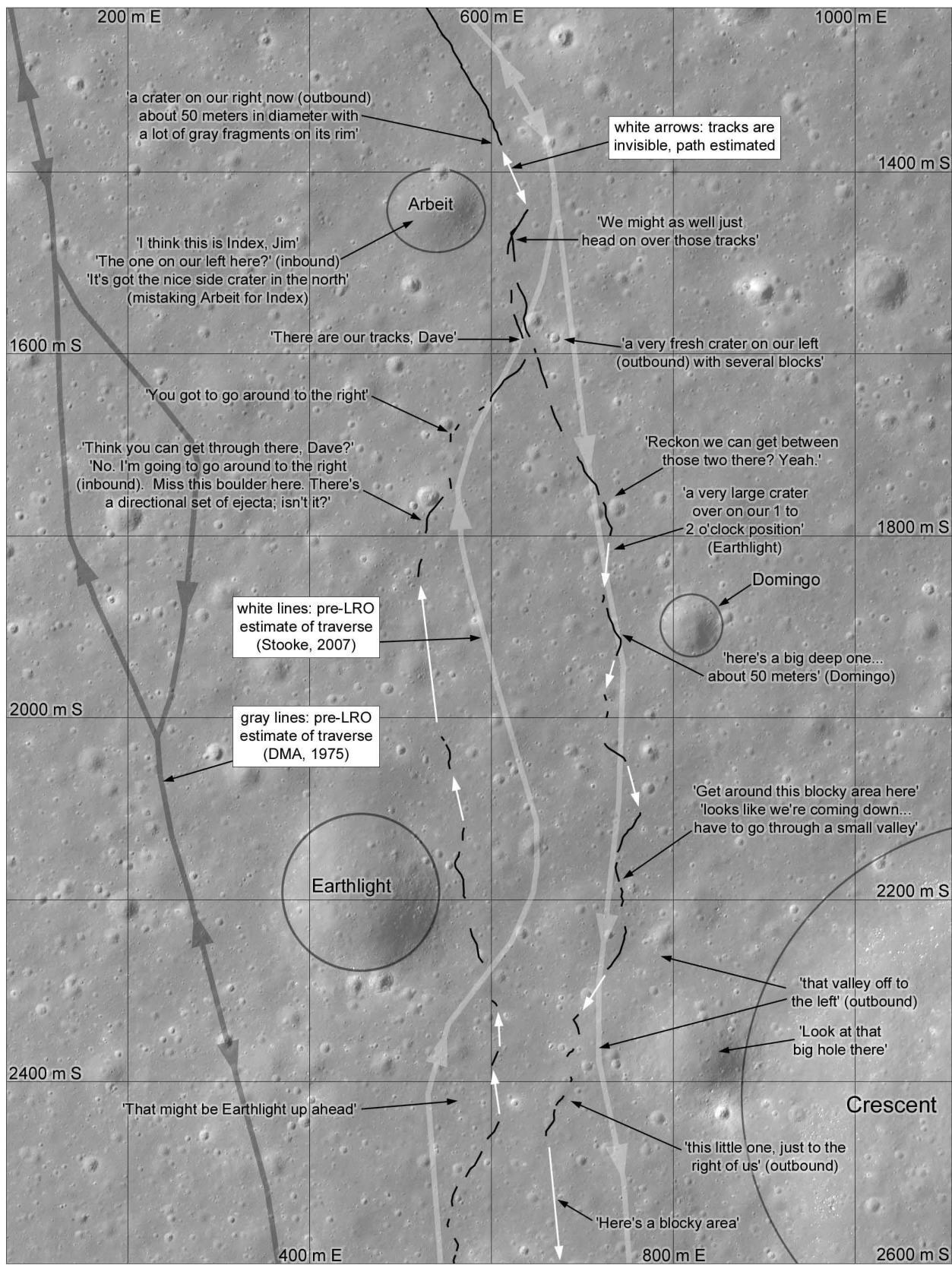


Figure 238. Apollo 15 EVA 2, map 2. White arrows show inferred routes where tracks are not visible.

Approaching Spur, they aimed for a parking spot near the northern (downslope) rim. The slope was less steep here, 10° at most, and Allen gave them instructions to park where good TV coverage could be obtained. Irwin climbed off and took a panorama while Scott worked on the antenna pointing. Irwin noted more green material in the regolith here, though changes in lighting and in its appearance when they raised or lowered their visors left them uncertain about the colour, and eventually they felt it was an illusion. Eventually, back on Earth, green glass beads were found in these samples, and in 2008 (Saal *et al*, 2008) water was found in small quantities in these beads, which had formed in an explosive volcanic eruption. They were probably transported to this location on the mountain as ejecta.

The astronauts noted an interesting block to their west, and after collecting rock and soil from the crater rim nearer the rover they were moving over towards the block when a remarkable target presented itself to them. This was a small white rock sitting on top of a clump of regolith, and as soon as they looked closely at it they both saw a distinctive reflection from its crystals, diagnostic of plagioclase feldspar. This was expected to be a major constituent of the Moon's original crust, forming a rock called anorthosite, and Scott immediately said 'I think we found what we came for'. They collected the rock, soon named 'Genesis Rock', and other samples from the vicinity, before moving to the larger rock to the west. One sample was half black and half white with an obvious contact between them. Another was a glass-coated breccia, another piece of ejecta. At one point Allen noted that Irwin had dropped a sample bag, and later that Irwin's sample collection bag (a large bag containing the smaller bags with their individual samples) was about to fall off his PLSS, showing the value of live TV coverage of operations.

Houston was anxious about time and now called on them to skip sampling the large block in favour of taking a rake sample, thinking that would produce a greater variety of small rocks. Scott moved over to photograph the rock and took a moment to pick up a small fragment beside it. Then he returned to the rover where Irwin was to collect his rake sample, and picked up another rock there as well. Scott cleaned dust off the TV camera to stop it overheating, and then helped Irwin bag the small rocks from the rake sample and picked up a glass ball which he likened to a marble. A second set of 500 mm telephoto pictures was to have been taken here, but had to be omitted. They continued collecting regolith and rocks as long as possible, then stowed samples on the rover and climbed on. Irwin again held on rather than attaching his seatbelt as they drove away.

Scott drove diagonally down the slope to the northwest, and Irwin turned the 16 mm camera on, capturing a brief video clip here. The elevated viewpoint allowed Irwin to survey the South Cluster, noting a fresh crater with many blocks east of Dune and speculating that they might be able to drive along Dune's eastern rim. They soon saw their tracks from the outbound drive and followed them northwards. The astronauts described again the linear features they could see on Mons Hadley, and other features they were passing. Allen advised them to head for the south side of Dune, which was thought to be a secondary crater from the Aristillus or Autolycus impacts to the north. The thinking was that ejecta from either of those craters would be more likely to be found downrange of the impact. Soon before reaching the Station 4 area Scott swung the rover off the existing tracks and turned east towards Dune. As they arrived at Station 4 Irwin was asked to turn the DAC off as it had probably run out of film, but he observed that it had only run for a short time and there was still film they could use later.

They dusted parts of the rover to prevent overheating again, and decided with Houston to omit TV coverage at this site. This was to be a short stop for a few rocks or a rake sample. Irwin took a panorama, but it was cut short by a camera failure and was less than half complete. The camera worked intermittently after this, at the LM, in EVA 3 and on the return to Earth, but it could not be relied on, so Scott took over many of the subsequent photographic tasks. The astronauts collected rock and soil samples quickly, Scott taking the standard before and after images and others to establish the locations of the samples. They found and sampled a big rock with many large vesicles (holes formed by gas bubbles in the lava before it solidified). After this short stop at Station 4 they boarded the LRV and drove away, first to the west and then northwards around the western rim of Dune. Irwin turned the 16 mm camera on and it worked properly during this part of the drive, allowing the route to be established precisely in an area where the tracks are completely invisible in LRO images. They soon found their outbound tracks and followed them almost exactly around Dune until the tracks swung eastwards along the northern rim. To save time they turned off the tracks and headed due north, and soon after that the 16 mm camera stopped working again. They could see the LM so leaving the tracks here was not a concern to them.

Scott drove north until he reached Earthlight, a crater named after an Arthur C. Clarke novel (Clarke, 1955), and passed it on its eastern side, close to the rim and about 200 m west of their outbound tracks. During the drive north from Earthlight Allen passed on instructions for their activities when they reached the LM. Scott was to unload their samples while Irwin checked his camera. If he could not make it work with the current film magazine he should replace it and then take three panoramas from positions around the LM, as had been done at the previous Apollo sites. Then he would take pictures of the descent engine, which had struck the surface during landing, and the SWC. Scott noted a distinctive linear ejecta pattern south of Arbeit, and Irwin observed that they were so dirty now that they would need to use the jettison bags on their legs again to keep the cabin clean. Allen passed on the news that the ALSEP, still 2 km away, could detect the motion of the rover, though in fact it had picked up the vibrations as far away as Station 6 at a range of over 5 km. Scott mistook Arbeit for Index until Allen corrected him, and turned to bypass it on its eastern side. They encountered their outbound tracks again (Figure 238) and turned north, running parallel to the old tracks until they reached Arbeit where Scott drove across them. This is where Station 8 would have been, but they drove on, turning slightly west towards the LM and now almost exactly following the outbound tracks.

Irwin, looking ahead, noted a bright rocky-rimmed crater and Scott suggested it was November (Figure 237), which was probably correct. That placed Index to their right. Soon they were describing a fresh rocky crater about 500 m south of the LM, and as they passed Last crater they could see their EVA 1 tracks as well as the outbound EVA 2 tracks. Scott said 'tracks upon tracks, Jim' and Irwin likened it to a freeway. They stopped near the LM and dismounted, and Allen instructed them through the new procedures, since the checklists they wore attached to their cuffs no longer matched the plan. Irwin could not make his camera work and suggested he and Scott exchange cameras for the time being. Scott unloaded samples and tools and prepared the LRV for his work at the Heat Flow Experiment (HFE), and soon drove out to it, parking east of the ALSEP to avoid throwing dust on the deployed experiments. He dusted parts of the rover to reduce heating as the dark dust absorbed sunlight, cleaned the TV camera lens, and pointed the antenna to support TV coverage of his work at the HFE.

Scott's main task here was to drill the second hole deeper, one or two additional drill stems more if possible. Allen advised him to put less pressure on the drill in the hope of avoiding the stem binding in the hole. As Scott was preparing to drill, Irwin took three panoramas around the LM and the other requested images of the SWC and the area under the LM. Then he removed the U. S. flag from the MESA for deployment later, and walked out to the ALSEP to take a panorama there. Scott applied the drill to the stem already in the ground, seeing if he could move it or raise it slightly and drill down again, but it was difficult to make any new progress with the hole. Suddenly, however, the drill stem seemed to break through a barrier and penetrate about 15 cm further. In fact, during an attempt to raise the drill stem, one section had separated from the other and then had pushed past the first on the way back down, making the effective depth of the hole less than anticipated. The plan had been to have two holes, each almost 3 m deep, but in fact drill hole 1 was about 1.5 m deep and this second hole was only 1 m deep to the bottom of the separated section.

Irwin checked the bubble level on the ALSEP Central Station while Scott tried to remove the drill, struggling with it as before and stumbling badly as he did so. Irwin then took the ALSEP panorama and photographed the Heat Flow site. When Scott removed the drill he added another stem and tried drilling deeper again, but made no significant progress. They gave up on the drilling now and he tried placing the heat flow probe in the hollow stem, but this also caused problems. The probe was designed to be pushed down the hole with a rod called a rammer, and Allen now suggested that Scott remove the probe and just push the rammer down the hole. He did so, and it penetrated about 1 m. Then he replaced the probe and tried to push it a little deeper, but soon gave up. The experiment was compromised but was still able to provide useful results (Langseth *et al.*, 1972, 1976; Grott *et al.*, 2010). Scott suggested drilling a new hole with the four unused stems he still had, but Allen said they were satisfied with what they had. Then Scott adjusted the electronics box for the HFE and removed any items close to the probe holes which might interfere with the experiment.

Irwin had been picking up rocks, one pinkish and one black, while waiting for the drilling work to finish. He and Scott moved a little to the east and started the Station 8 activities together. They chose an undisturbed area among the various tracks, and Irwin began digging a trench with a scoop. Scott had taken his camera back from Irwin after finishing the HFE work, and now took a panorama of the site. Irwin found the digging easy here and quickly excavated a trench about 40 cm deep with a smooth near-vertical wall in the fine regolith. He found a few fragments but saw no layering in the wall, and found the subsurface material much harder below about 30 cm depth.

He had to widen the trench to accommodate their penetrometer. Scott photographed the trench and then helped Irwin collect a sample from the hard material at the bottom of the trench, placing it in a Special Environmental Sample Container. Irwin then sampled more material from the bottom and the top of the trench, omitting planned samples at different depths in the wall because he saw no layering.

Scott began drilling to obtain a double core sample, finding it relatively easy to drill down, but hard to remove his drill afterwards. Irwin used the penetrometer to measure the hardness of the material at the surface just outside the trench, then at the bottom of the trench, and finally on and then beside the very fresh rover tracks just behind the LRV. He then made a second measurement with different settings on the floor of the trench, and finished this task by pressing hard on the surface outside the trench until the wall collapsed. These observations provided information of regolith properties which might be valuable for future engineering work on the Moon. Scott had managed to free his drill and added two more drill stems, experiencing some difficulty threading the stems together. Time was running out quickly on this EVA, but he managed to finish the drilling to a suitable depth and was asked to loosen the stems in the soil and leave the drill on top of the stems until EVA 3.

Scott returned to the rover to drive it back to the LM while Irwin photographed the penetrometer sites and the drill, and then walked back to the LM. Scott arrived soon after and parked the rover north of the MESA. He brushed dust off the rover to reduce heating as the Sun rose higher in the lunar sky. Irwin stowed samples, experiencing such difficulty closing one of the sample boxes that Scott had to help him. Scott became uncharacteristically frustrated with the constant stream of requests from Houston and had to ask for a few minutes of peace. Then the US Flag was set out, and the obligatory photographs of the astronauts beside it were supposed to be taken, requiring an already stowed camera to be unpacked for the task. Irwin pushed the base of the flag support into the ground and hit it with the flat of his hammer to be sure it was firm. Then he fetched the flag, mounted on a staff and crosspiece, and attached it to the base as the TV camera recorded the deployment. Scott took pictures with a black and white magazine showing Irwin saluting the flag, and then Irwin took pictures of Scott. They did not have a colour film magazine handy so those photographs were postponed to EVA 3.

Wrapping up EVA 2, they prepared the rover with a final brushing and by opening battery covers. They brushed as much dust as possible off each other. Irwin climbed up to the LM cabin to pass out the LEC lanyard, and Scott carried the sample box which had been hard to close up the ladder to the cabin. The TV camera, controlled from Houston, panned upwards to view Earth, now in a crescent phase high to their south. It stuck in that position, and Scott had to free it when he descended again a few minutes later. Now they used the lanyard to transfer an equipment bag up to the cabin, but Scott decided it was easier to carry up the remaining two sample bags himself. The LEC was not used again on Apollo 15 and was omitted altogether from the last two missions. Scott returned to the rover to turn off the power and then climbed into the LM himself. The cabin was even more crowded now with the samples and other items, and Irwin had to guide him in.

Once inside, they turned each other's water valves off. Even on the surface towards the end of each EVA when cooling water ran low and had to be switched to an auxiliary source, they usually had to do this for each other because their suits made some movements difficult. Then the cabin was pressurized and the suits could be reconfigured and eventually removed. Their hands were tired and sore from working in the gloves for so long. The EVA had set a duration record, 7 hours and 13 minutes, and had covered 12.5 km. Their oxygen use had been normal, not elevated as in EVA 1. Irwin's suit leaked a little water until they got its switches configured properly. The samples were weighed to help estimate the LM take-off mass, and various items had to be configured and prepared for the sleep period and the next EVA. Houston did not need a science debriefing for this EVA, but Scott and Irwin were able to talk to Al Worden as he passed over the landing site again. The crew took a short time to eat a meal as the PLSS water reserves were recharged, and set out their hammocks for a 7 hour sleep period.

A ship called Endeavour was navigating through the Northwest Passage during the Apollo 15 mission and the two crews had been in contact earlier. Irwin asked if there was a message, and there was indeed one from the ship to the spacecraft, which was read to them. Houston also passed up a message that the flight surgeon wanted some sensor fittings changed next morning. At last the day's work was done and the astronauts began their sleep period.

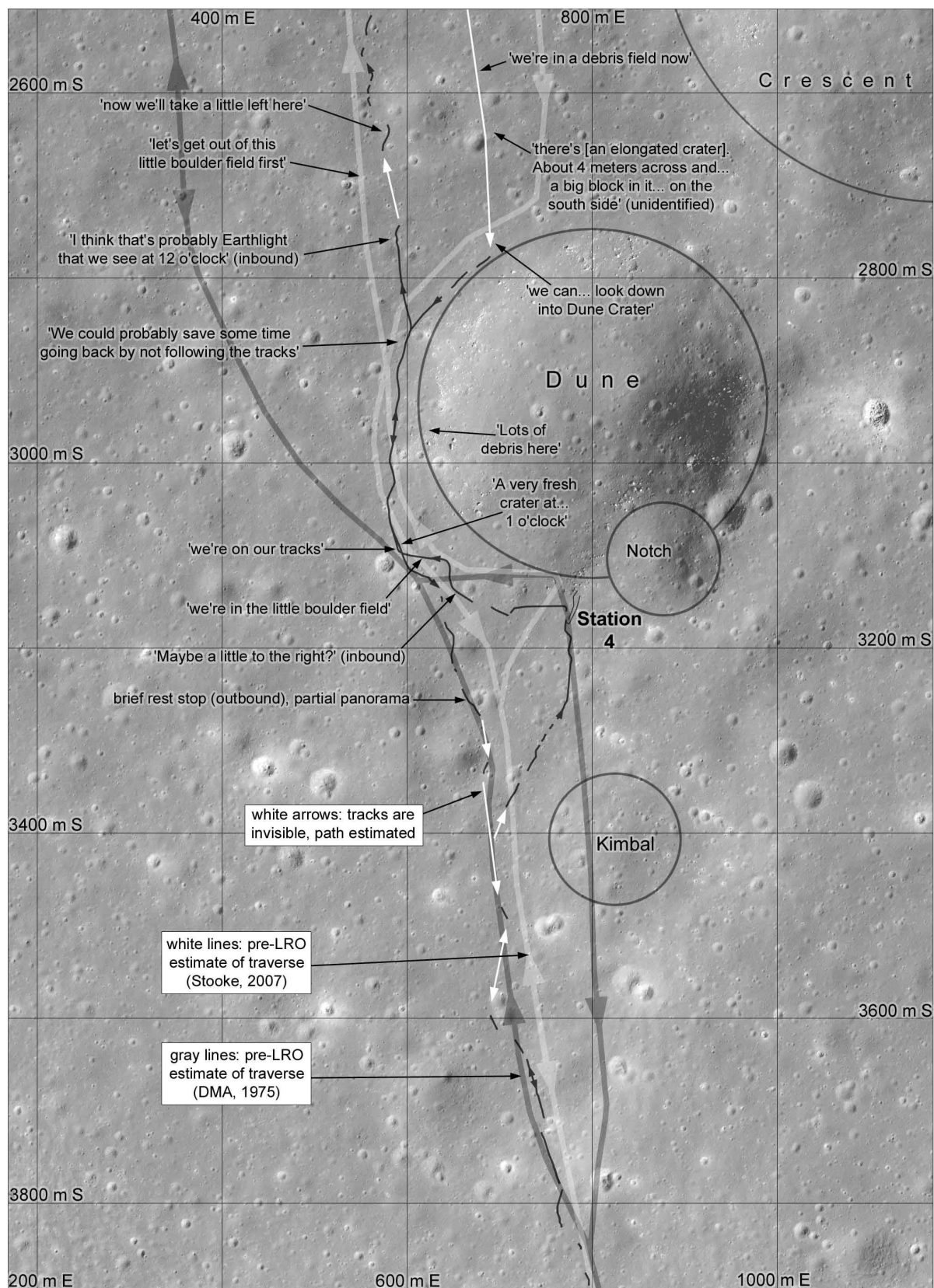


Figure 239. Apollo 15 EVA 2, map 3.

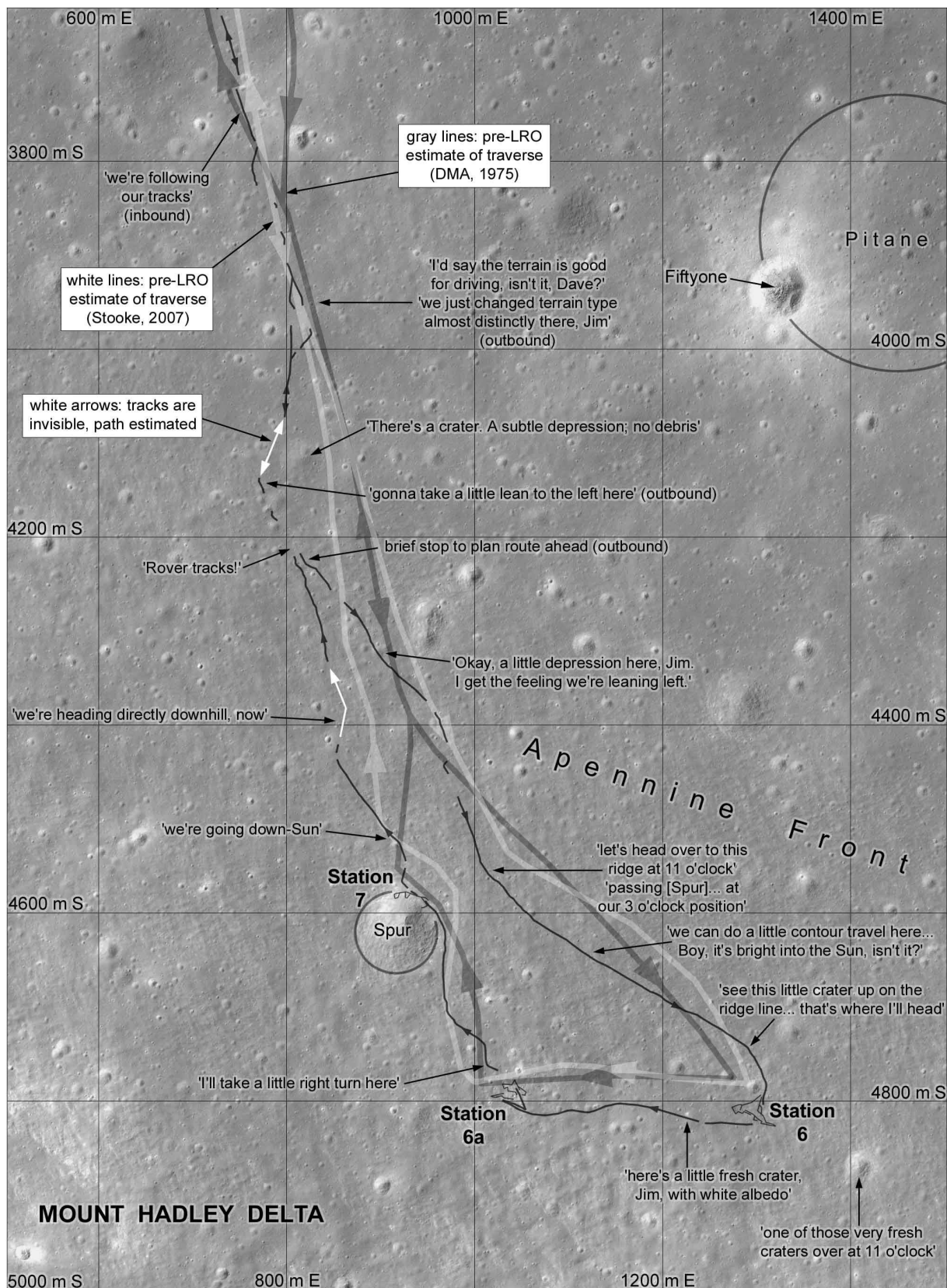


Figure 240. Apollo 15 EVA 2, map 4.

Scott and Irwin were woken with a call from Houston after a 6.75 hour sleep period, and as soon as they started moving in the cabin the ALSEP seismometer detected the vibrations. They were given lists of departure times in case an early liftoff was required, and updated on LM power, oxygen and water levels. The third EVA would be cut short because their sleep period had started and ended later than scheduled but liftoff would occur according to the original plan. It was expected to last about 4 or 5 hours, and its actual duration was 4.85 hours. The mission had already achieved its requirements for full mission success.

The camera which failed during EVA 2 had been cleaned before the sleep period, and worked for part of EVA 3 but was still unreliable. Scott thought the problem was caused by dust entering the camera, but it was eventually traced to a mechanical fault. They put their suits on and Houston checked their biomedical sensor data. Then the crew were updated on current plans for the EVA. They were to extract the double core at the ALSEP site, take some images of the rover being driven through a test circuit called a 'Grand Prix' for engineering purposes, and then drive to the edge of Rima Hadley. The original plan (Figure 241) included a supplemental sampling stop on the way to the rille (and a second one on the way to North Complex), shown on their map as triangles, a Greek upper case Delta symbol, and now referred to as Delta by Allen. This would be omitted to save time. The activities at Stations 9 and 10, sampling and photography, would be conducted as planned, and at Station 10 Houston would decide whether to drive to North Complex or to return to the LM. The return trip would cross a shallow crater group called Alligator Chain (Figure 241) and stop at a new Station 14 at Quark West, the western crater of the Quark triplet. The original Station 14 was further north at a crater called Ring. Scott hoped they could reach North Complex. The earlier estimated route of EVA 3 in Figures 241 and 242 is taken from DMA (1975). The planned EVA is taken from MSC (1971).

The astronauts checked communications, had a last drink of water from the LM water system and secured their helmets and gloves. The LM was depressurized and the last EVA began. Scott climbed out and dropped a jettison bag of unwanted items to the south of the ladder. The rover was powered on and they loaded camera film magazines and prepared for the traverse. Allen read out instructions for the drill core extraction. Irwin photographed the rover, including a placard reading 'Man's First Wheels on the Moon, Delivered by Falcon, July 30, 1971' with the crew names and signatures. These were not really the 'first wheels' as Lunokhod 1 and the Apollo 14 MET had wheels, but 'wheels' can mean 'car' in American slang, and this was the first such vehicle on the Moon. They also took colour photographs of each other at the flag to supplement the black and white pictures taken at the end of EVA 2, before Scott drove the LRV out to the drill area.

Irwin walked to the ALSEP, and at some point while he was still near the LM he deposited several personal items on the lunar surface and photographed them. He did not say anything, so it is difficult to be sure exactly when and where he did this, and although the images show some rover tracks it has not yet been possible to locate the site. These items were silver plates carrying the fingerprints of his wife and children, a microfilm copy of an Apollo 11 commemorative booklet, a small piece of lava from Oregon where the crew had done field training, and a photograph of a man called J. B. Irwin (astronaut Irwin's middle initial was also B, for Benson). The photograph was provided by the man's daughter, who said he had wished to go to the Moon and had died before the Apollo 11 landing.

At Station 8 they set up the TV to view their activities, and then they worked together to pull the drill up. It was difficult to extract from the ground and looked as if it might have to be done one section at a time. Scott asked if it was really worth the time it would take, but the scientists in Houston regarded it as very valuable. Eventually it was removed when the astronauts stooped to position their shoulders under the drill handles and pushed upwards as hard as they could. The TV camera had not been able to tilt up to view the action, so Scott now moved it for the benefit of viewers on Earth. They tried to break the stems apart, cap them and stow them for return to Earth, but this also proved very difficult. Irwin left that task to photograph the trench he had dug on EVA 2 and started to take a panorama of the ALSEP area. After taking 4 pictures his camera jammed again and he used Scott's camera to take a full panorama. Then he returned to the drill task, which was making Scott increasingly frustrated. Finally the job was abandoned for the time being with four of the sections still joined and two separated and capped.

The last task at Station 8 was for Scott to drive the rover in a 'figure 8' path they called the Grand Prix, while Irwin filmed it with the 16 mm camera. This was to provide information on the behaviour of the vehicle under lunar conditions, including traction, steering, braking and acceleration, and the dust thrown out by the wheels. The 16 mm

camera did not work and the experiment had to be repeated on Apollo 16. Irwin mounted the rover and they set off for the rille, passing north of the ALSEP (Figure 242) and noting several glass balls on the surface. They noted a large depression ahead of them and turned to the north again to avoid a smaller crater in its deepest part. Irwin said he would name the depression Wolverine after the University of Michigan sports teams. All three Apollo 15 astronauts had attended the University of Michigan. Before leaving Wolverine they stopped very briefly for Scott to photograph an interesting rock, as Irwin's camera was not working.

They drove through and around several other depressions here, and Irwin likened the topography to large dunes in the sense that the surface was smooth but distinctly undulating and visibility was limited. They turned south and then west again as they threaded a path through the hollows. Soon they saw fresh blocks around the rim of a crater which they referred to as Scarp, though the real Scarp crater was a subdued depression north of them (Figure 242). Scott parked just beyond the blocky crater and they walked back to sample its ejecta (Figures 242, 244), unfortunately moving into an area where the rover TV camera would not be able to see them working. This was Station 9, and from here they could see into Rima Hadley, but not to its bottom, so the rille photography would need to be done further to the west at what was designated Station 9A. Irwin tried to make his camera work again but failed, and Scott took a panorama from the rim of the blocky young crater, noting a 'bench' or ledge around the inner wall. The astronauts collected samples of the ejecta, mostly consisting of crumbly clods of regolith fused by the impact.

Joe Allen, in Houston, advised them that the Command Module had made a plane change maneuver to accommodate the rotation of the Moon under the spacecraft's orbit plane. This put the command module in position for the LM to rendezvous with it later in the day. Scott made another futile attempt to fix Irwin's camera, but they gave up and boarded the LRV to drive to the edge of the rille. Scott left the TV camera on, hoping Houston would see the drive as it happened, but the high gain antenna pointing varied too much to provide a good signal. They reached a shallow terrace, already named The Terrace on mission maps, at the edge of the rille with a spectacular view into the valley and stopped at Station 9A (Figure 244). Scott dusted the TV camera lens to be sure the picture would be clear for viewers on Earth, and then took the camera with the 500 mm telephoto lens to photograph the far wall of the valley, where layered outcrops were exposed. Irwin used Scott's camera to take a panorama of the site and then used a scoop to collect samples, including a vesicular basalt. He photographed a larger rock nearby with many vesicles. Scott tripped over a rock and fell forwards at one point, dropping the camera, but quickly recovered and joked with Allen about blowing dust off the lens.

After the photography both astronauts moved closer to the edge of the valley to collect more samples from some of the numerous large blocks (Figure 244). Irwin thought he could see exposed bedrock in place, rather than loose blocks, and asked if they had time to sample it. Allen said they could do so and would give up on the mare sampling stop they had called Station 14 at Quark West. In the end this was not possible but they sampled a variety of blocks. From the perspective of the TV coverage they seemed to be working at the very edge of the steep slope, and Scott had to reassure Allen that they were still some way back from the valley wall. They headed back to the rover and Houston asked for a rake sample and a double core before leaving the site. Irwin used the rake while Scott photographed the activity to record its location. Then they sampled some regolith and Irwin hammered the double core tube into the ground, surprised that it did not hit a buried rock. Scott and Irwin then collected two more rocks including one referred to later as 'Great Scott'. At the rover they dusted the top of the TV camera, which was heating up more than desired, and then drove northwest past a large boulder to reach Station 10.

Scott parked just north of Rim crater, which he mistook for one of the Twin craters nearly a kilometre to the north (Figure 244). Irwin dismounted and took a panorama from the rim of Rim crater while Scott used the 500 mm camera to photograph the far wall of the rille again. These images combined with the pictures from Station 9A provided stereoscopic views for detailed geological analysis of the outcrops. Irwin described and photographed a large vesicular boulder, and they were soon back on the rover and heading back to the LM. The delay with the core at Station 8 prevented a trip to the North Complex. Scott swung the rover round clockwise and they headed southwards to get around a large depression, Scarp crater, which they did not recognize. They moved northwards again but encountered North Ray (Figure 242) and turned east and then south again. North Ray was not a fresh ray crater, unlike the feature with the same name at the Apollo 16 site. A version of the EVA 3 planning map dated July 1971 also used the name North Ray, this time at the north end of Alligator Chain, but was not clear about which crater it applied to.

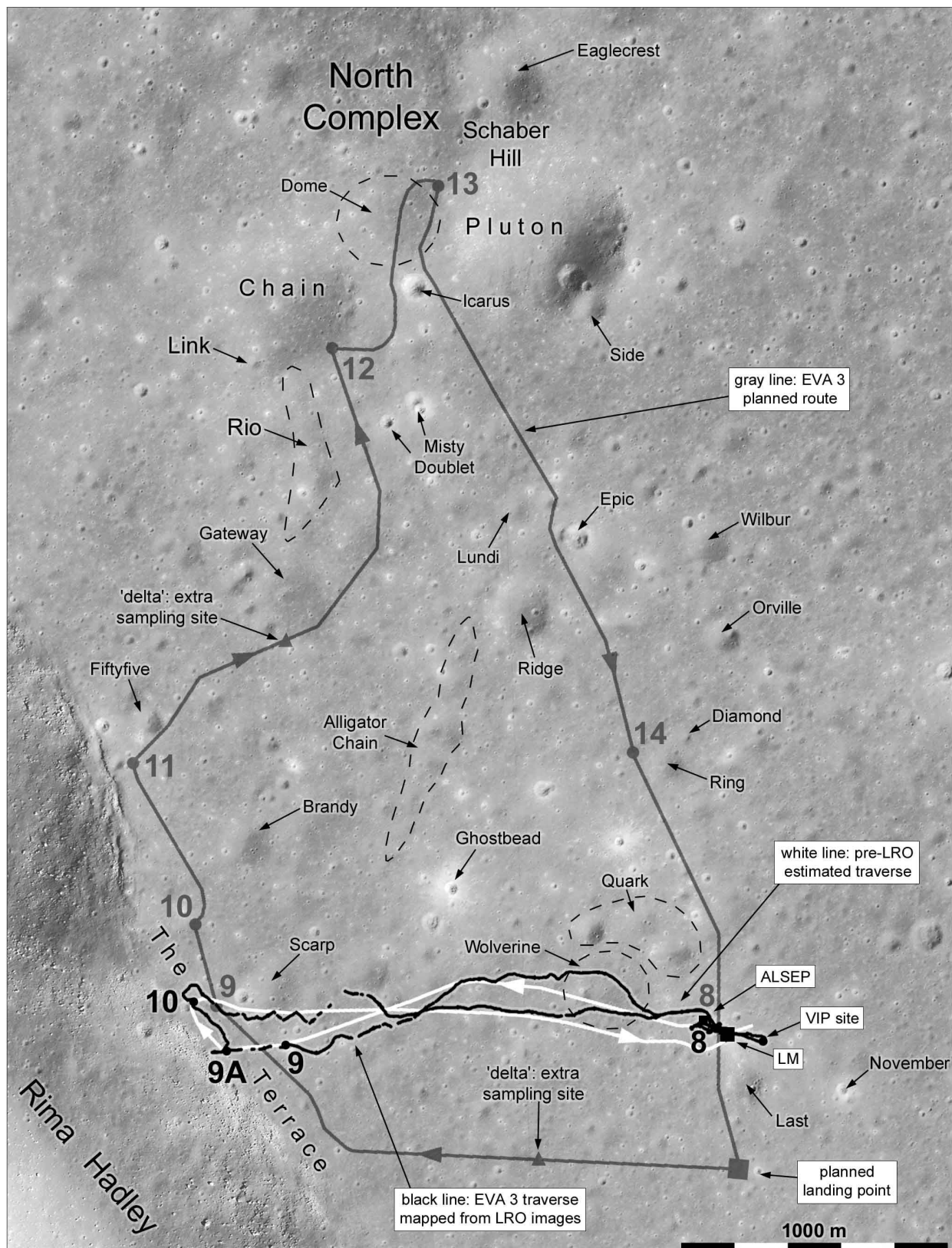


Figure 241. Apollo 15 EVA 3.

As they drove Allen gave them some suggestions for tackling the long core stem, which was still in one piece. It might fit in the LM as it was but they preferred to break it into two sections if possible. Irwin described rock outcrops he could see on Big Rock Mountain. They crossed their outbound tracks at about the same time that they noted they could see the top of the LM, and later passed right through Wolverine. As they climbed out of that depression the LM appeared again and they stopped briefly to photograph it. Scott followed their tracks north of the ALSEP and stopped again for another LM image before halting briefly at Station 8 for the last time. Irwin dismounted and picked up the long core and a part of the drill system, which he carried back to the LM. Scott drove to the LM and parked north of the MESA.

They started the TV and had to free the camera, which often seemed unable to move just after being turned on. Scott photographed the rover to document its condition and dust cover, and then the astronauts turned to the drill core task. The TV became stuck again, pointing straight up, and Irwin tilted it down, but it dropped down further and jammed again. Scott worked with the core stem, and unexpectedly found he could twist one section free with his hands. He left the three remaining sections joined as they would fit in the LM like that, and moved to point the camera again. These TV pointing problems resulted in a successful redesign for the next two landings. Irwin was still trying the 16 mm camera and found it would run for a few seconds and then stop.

The crew worked to stow their samples and film magazines. Scott photographed the rover deployment mechanism which had caused difficulty early in EVA 1, the damaged descent engine bell which had contacted the ground during landing and buckled, and a jettison bag under the LM. They scooped a sample of regolith from under the LM which might be contaminated by descent engine exhaust and placed it in one of the vacuum-sealed Special Environmental Sample Containers. Then Scott photographed the SWC and Irwin rolled it up, with some difficulty, and stowed it. Scott took some final 500 mm photographs of the mountains. Then they moved to the MESA for some final tasks.

Scott cancelled a U.S. Postal Service 'first day cover' new issue stamp commemorating US achievements in space with a picture of the LRV. The cancelled First Day Cover is now in the National Postal Museum in Washington, D.C. Nearly 250 covers were taken to the Moon but only one was cancelled there. At the request of a German stamp dealer, almost 400 additional covers were taken to the Moon and returned with an agreement that they would not be sold until after the Apollo program ended. The Apollo 15 crew and the dealer each had about 100 of these covers. When the stamp dealer began selling his covers early the crew backed out of the deal and did not benefit from the sales, but the astronauts were severely reprimanded for their part in the scheme (Irwin and Emerson, 1973; Chaikin, 1994; Slayton and Cassutt, 1994; Worden and French, 2011; Collectspace.com, 2020.)

Next Scott held up a falcon feather and a hammer for the TV camera and dropped them simultaneously to demonstrate Galileo's contention that objects of different mass fell at the same speed, contrary to a teaching of Aristotle. Galileo was said to have performed a similar experiment with large and small weights from the Leaning Tower in Pisa, Italy. The falcon feather was from the Air Force Academy in Colorado Springs, whose mascot is a falcon. The feather and hammer indeed struck the ground at the same time. The two items were then pushed out of the way under the LM.

After checking that nothing important had been left on the rover, Scott drove it out to the east from the LM. He had forgotten to set the navigation readings and may have looped back briefly to reset them near the LM before heading out again. He drove eastwards about 150 m, turned south and looped around to park facing the LM. The rover was left here at the 'Rest in Peace' site so the TV could record the LM liftoff. The camera had been turned off because it was getting very hot, but Scott brushed it clean of dust in the hope it would cool enough to use again. The additional warmth of the higher Sun was distinctly noticeable to the crew during EVA 3.

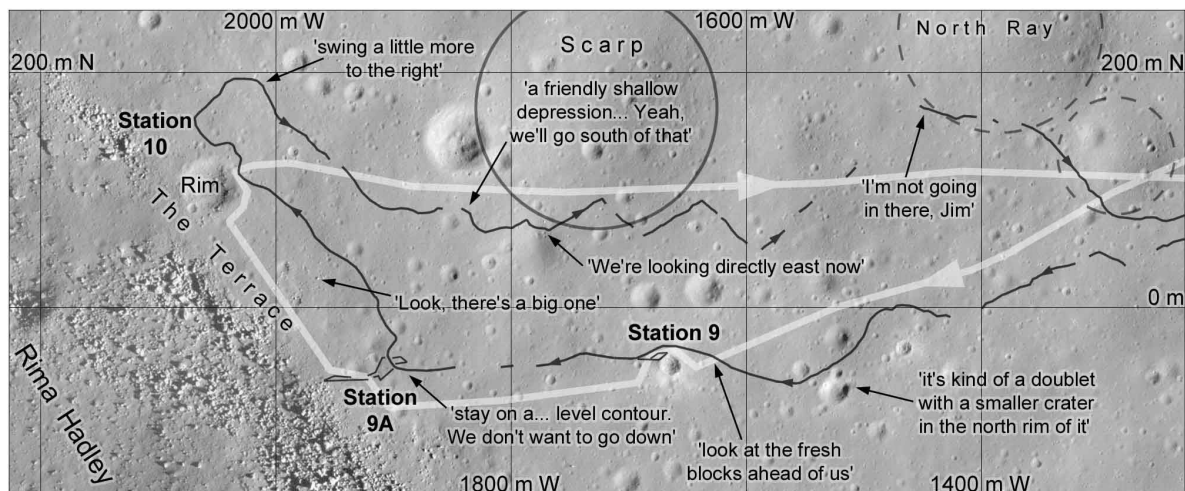
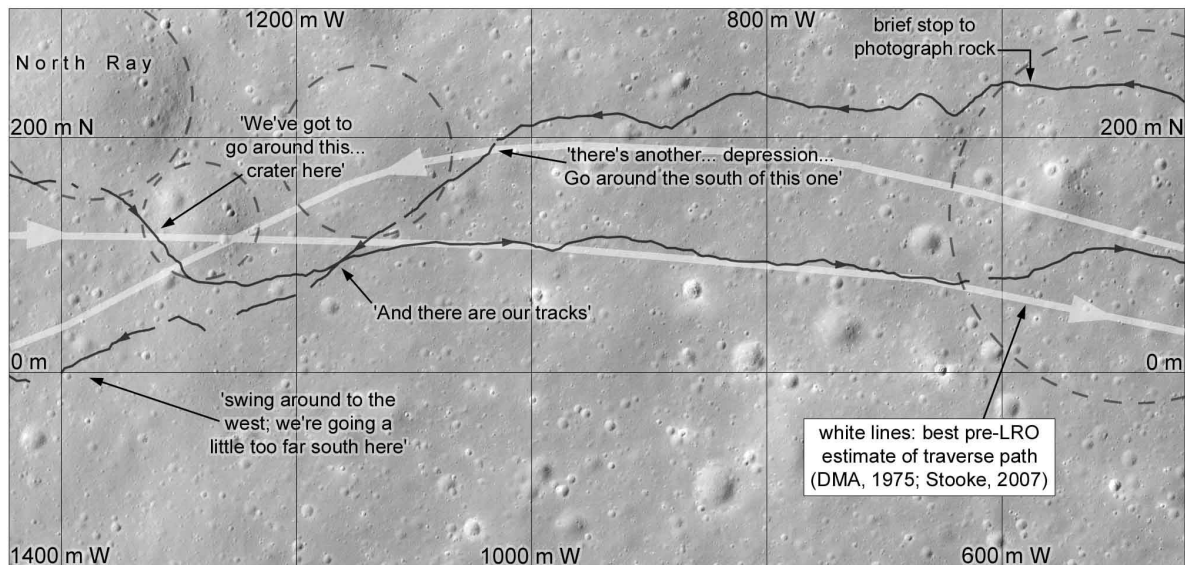
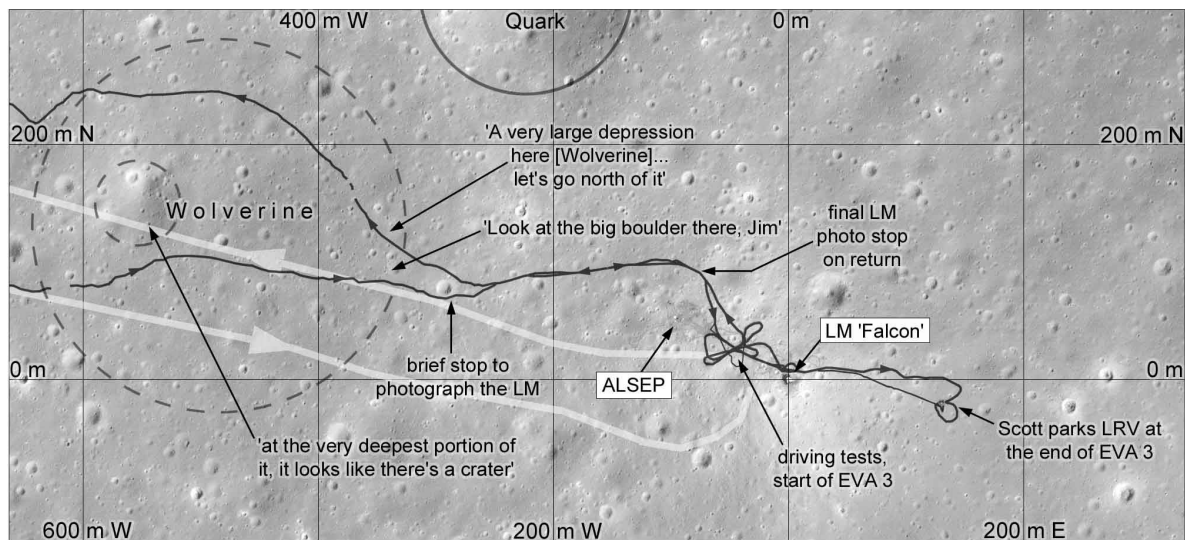


Figure 242: Apollo 15 EVA 3.

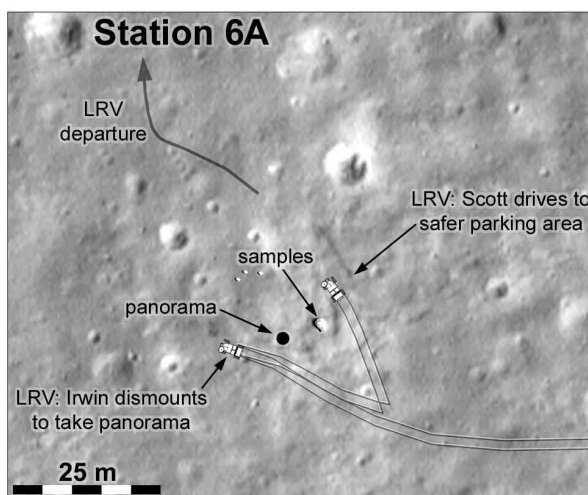
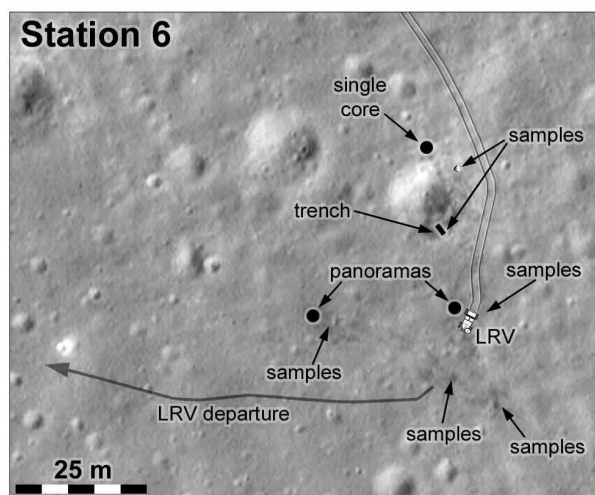
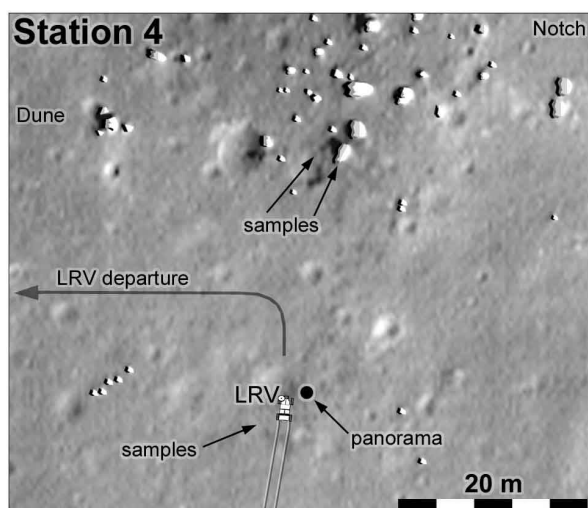
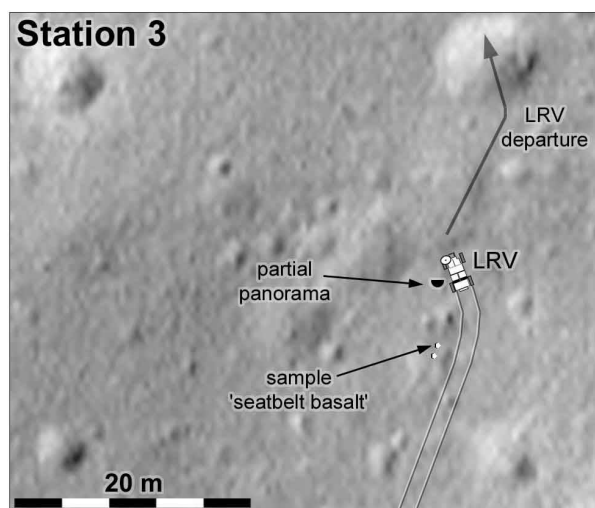
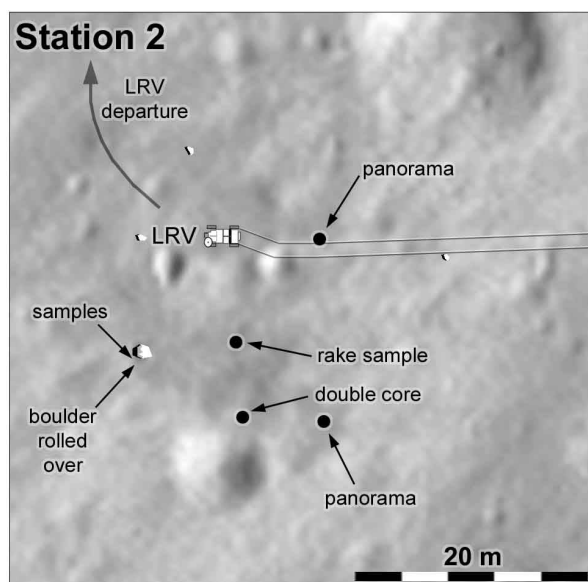
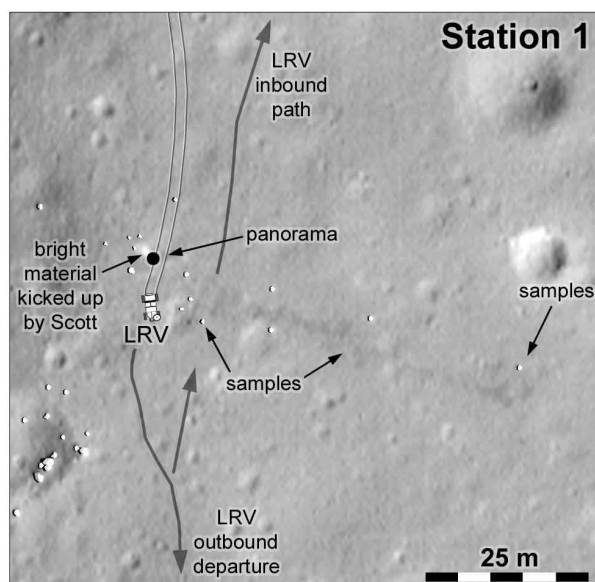


Figure 243. Apollo 15 stations 1 to 6a.

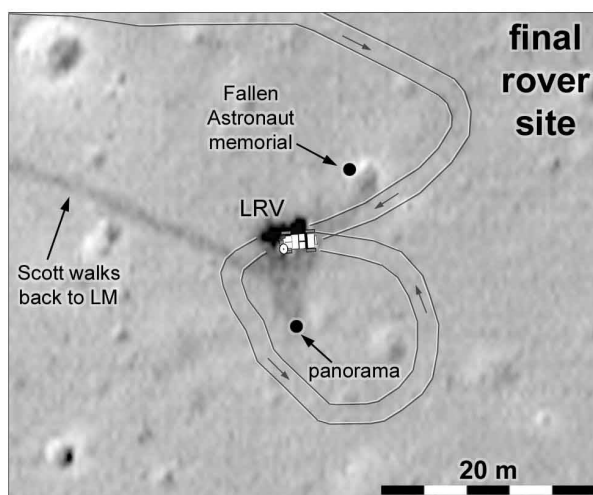
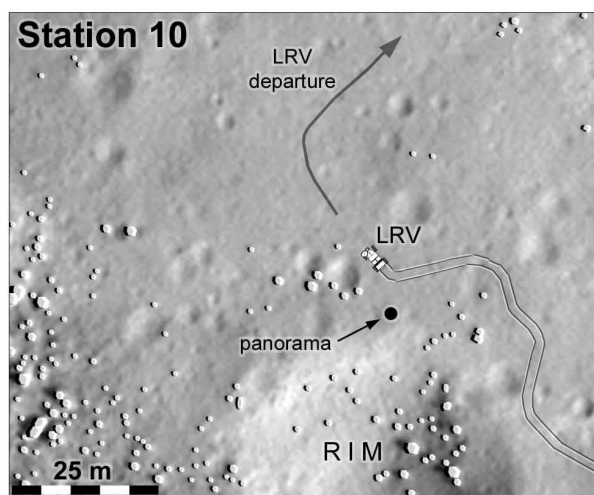
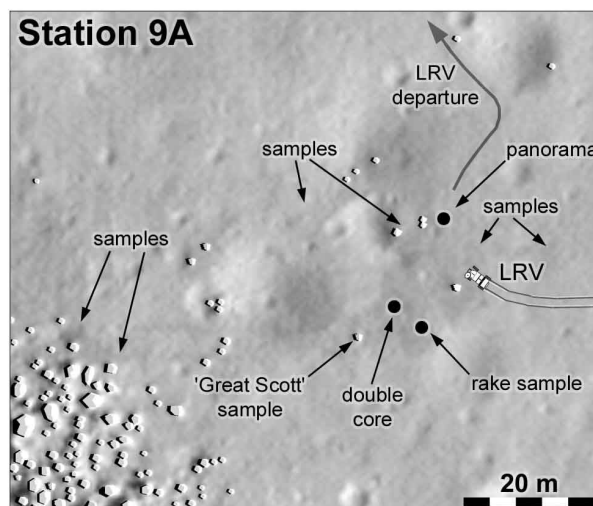
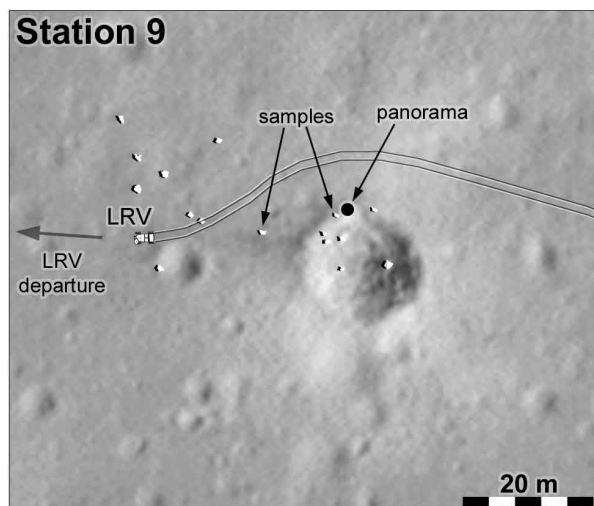
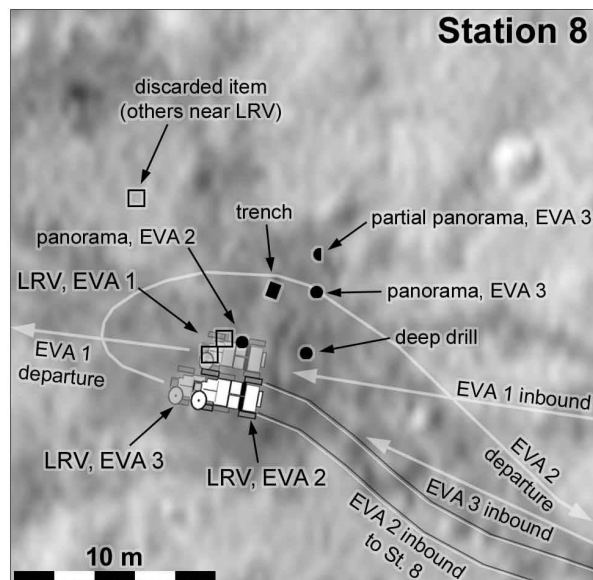
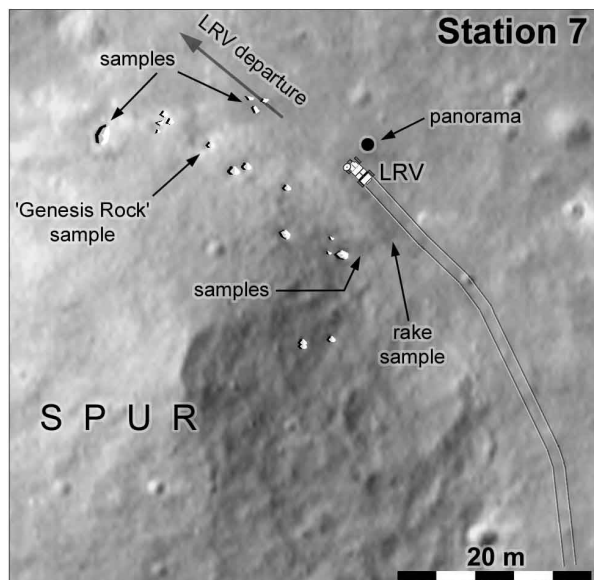


Figure 244. Apollo 15 Stations 7 to 10 and the final rover site.

Scott prepared the rover for departure and quietly deposited a memorial to dead astronauts and cosmonauts on the surface near the rover (Figure 244). This included a small plaque listing the names of people who had died during space flights or related activities, and a small sculpture of a 'fallen astronaut'. This was provided by the Belgian artist Paul van Hoeydonck, who later went on to sell copies of the sculpture which may have contributed to the controversy over stamp sales. The 14 names on the plaque included the Apollo 1, Soyuz 1 and Soyuz 11 crews and others including Yuri Gagarin who had died in accidents. Valentin Bondarenko (Figure 215E) was not included as his death had not yet been made public. The memorial was not publicized until after the return to Earth. Then Scott checked the LRV antenna pointing for the TV, pointed the camera properly because it could not be controlled easily from Earth, and took a panorama before returning to the LM.

Meanwhile Irwin was carrying bags up to the LM porch. Scott returned and they dusted each other off as much as possible. Irwin entered the LM and stowed the items he had carried up, including the long core. Scott brought up the remaining items and entered the cabin himself. Soon they repressurized the cabin, ending the EVA after 4 hours, 50 minutes, and Flight Director Gerry Griffin congratulated them. They prepared for departure, including weighing their samples to help plan the liftoff burn and taping the caps on the long core in case they came loose during the subsequent depressurization, when they jettisoned the PLSS units and other unwanted items. Ed Mitchell, the Apollo 14 astronaut, came on as CapCom to work with them through the critical liftoff and rendezvous operations. They photographed the scene outside the LM windows, showing their complex tracks (Figure 246).

After a long series of checks and preparations, the LM lifted off at 17:11 UT on 2 August and for the first time was filmed by the LRV TV camera as it departed. Unexpectedly for the LM crew and the team in Houston, Al Worden in the Command Module played a tape of the Air Force Song on a tape recorder during the ascent. Many items were thrown out from the LM by the ascent engine exhaust, all light insulation blankets and covers. A particularly large one from the MESA was ejected towards the ALSEP and landed only about 10 m north of it before rolling out another 70 m or so. This could have damaged the ALSEP and suggested that loose items should be stowed more carefully before departure on future landings. Scott and Irwin had an excellent view of Rima Hadley as they ascended and turned to the west, commenting on boulder tracks extending down its walls. The LRV camera viewed the liftoff and continued to function for about 3 more days, occasionally commanded to survey the scene, until it failed suddenly. If it had survived for one more day it might have observed a solar eclipse (lunar eclipse for viewers on Earth).

The LRV continued to function for several days after the LM ascent stage liftoff, and was used to transmit several TV panoramas. It could not be driven remotely, though that option had been considered earlier (Figure 121B). An attempt to transmit TV coverage during a solar eclipse (lunar eclipse as seen from Earth) on 6 August was prevented by a permanent loss of transmission the day before. The crew, then more than half way home, offered to return to make repairs.

Plans of the Apollo 15 stations, or sampling stops, are shown in Figures 243 and 244 with the locations of panoramas, sampling sites, cores, trenches and other activities. They are drawn on enlarged LRO images with details based on small drawings in Swann *et al.* (1972), except for Station 6A which corrects an error in that paper according to an analysis by Eric Jones for the Apollo Lunar Surface Journal. The LRV locations and tracks are shown at the time of the station operations, with tracks and other details taken from rectified panoramas. Details of craters and rocks are based on a composite of the sketches in Swann *et al.* (1972), LRO images and rectified panoramas. At Station 2 a boulder was rolled over and samples collected from underneath it. The rake samples (Stations 2, 7 and 9A) were intended to collect small rock fragments from the soil. Station 6A was the highest point reached by the astronauts. Station 10 was chosen to provide stereoscopic images of the far side of the rille in combination with Station 9A photography. No sampling was done there. The final LRV parking site is also illustrated.

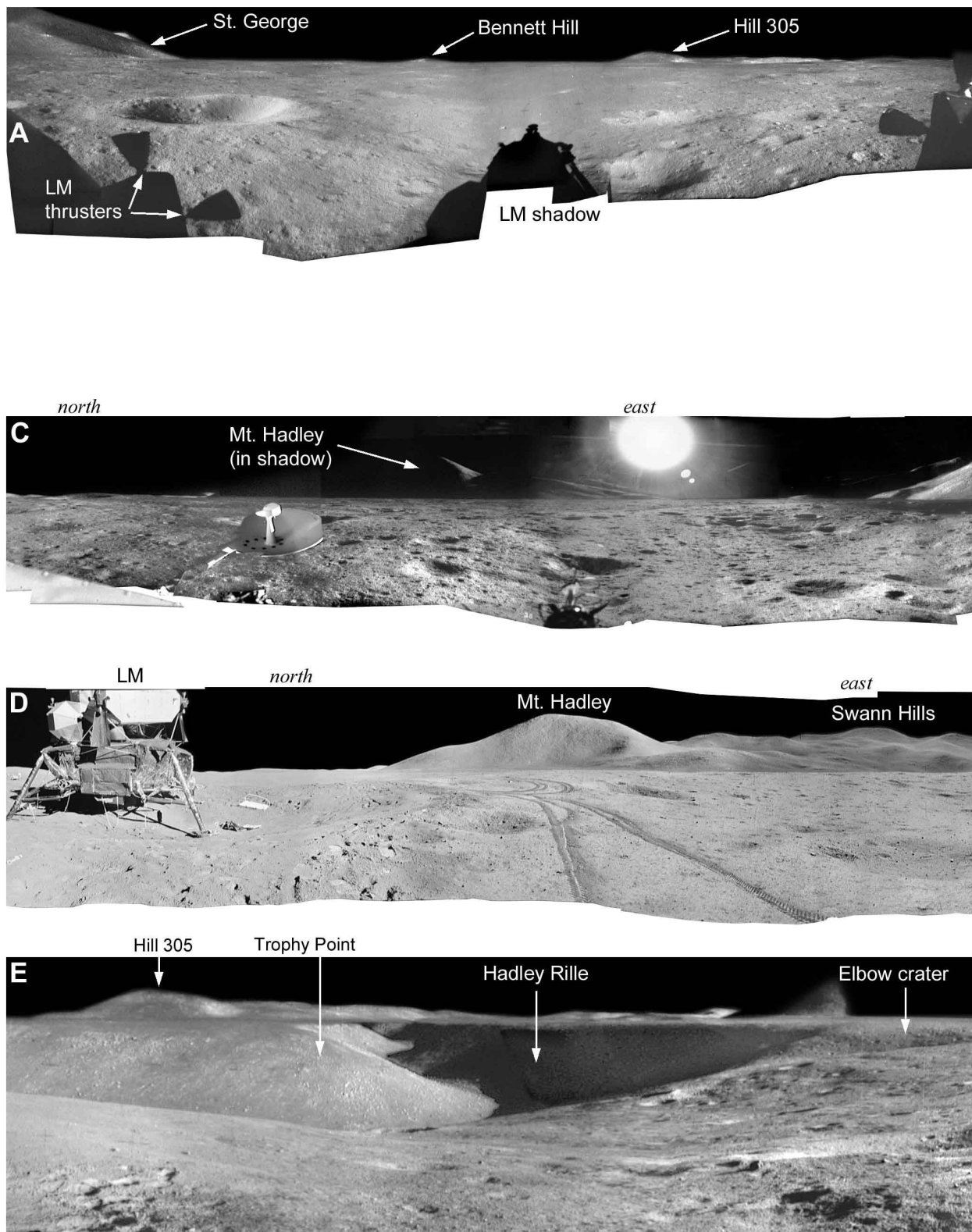
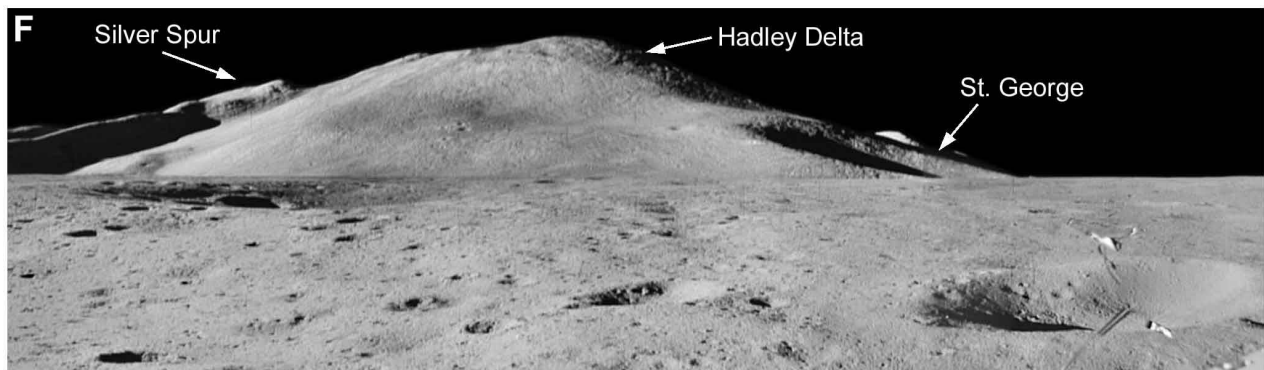
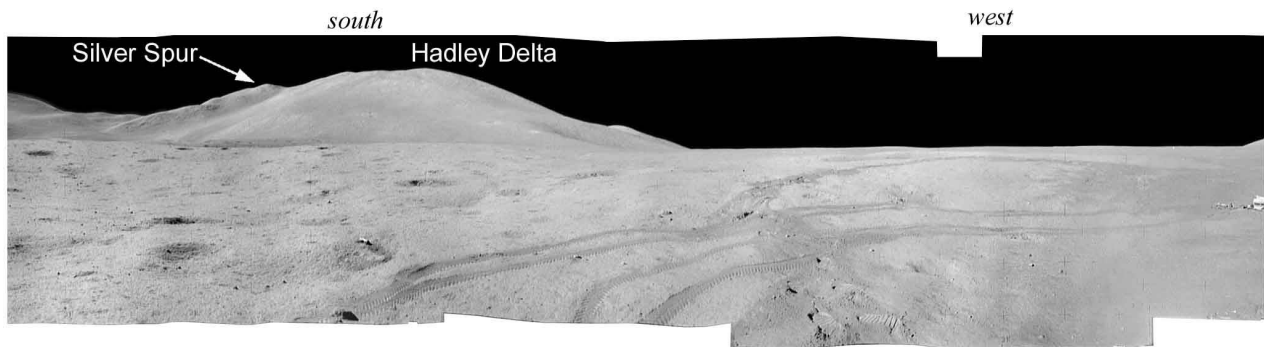
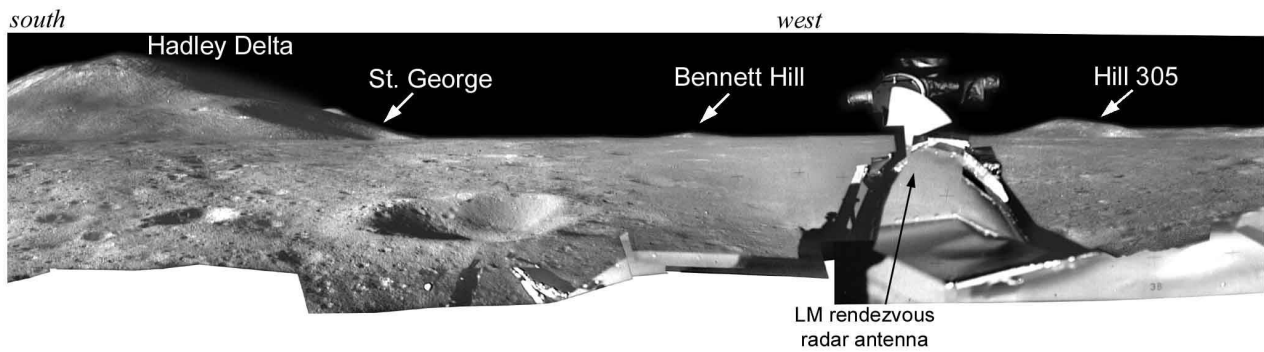
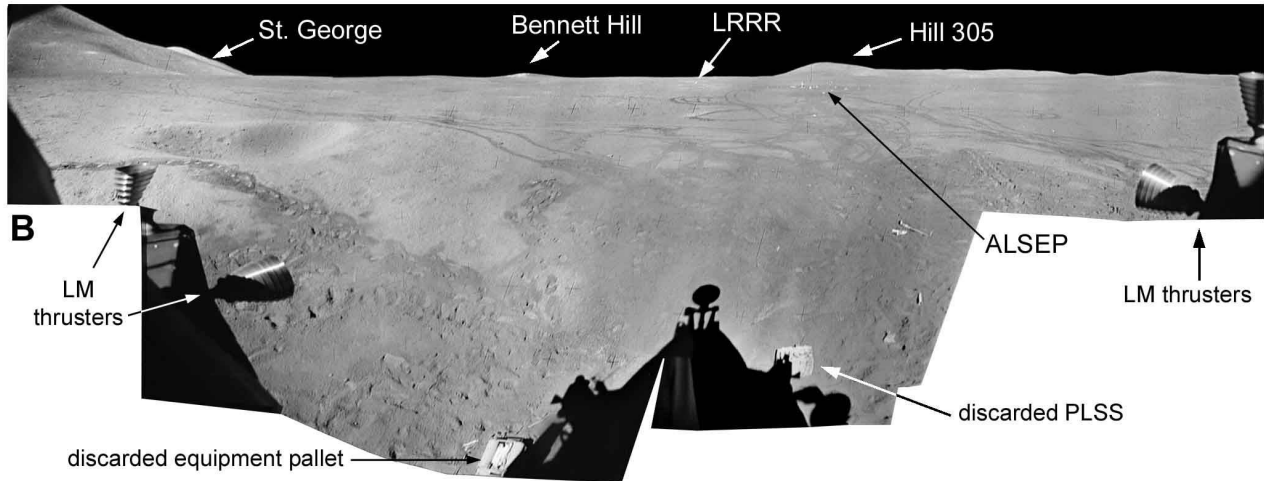


Figure 245 (both pages): Apollo 15 panoramas. A, B: composite views looking west from the LM windows, just after landing (A) and after EVA 3 (B). C (across both pages): Stand-up EVA (SEVA) panorama. LM components are truncated because image overlap areas have been edited to maximize surface visibility.



D (both pages): panorama made at the end of EVA 2 just south of the LM. E: view to the north up Hadley Rille from Station 2. F: view south to Hadley Delta from the LM during the SEVA. The large crater at left is Last. An antenna at far right, partly obscuring a small crater, has been mostly edited out by combining overlapping images.

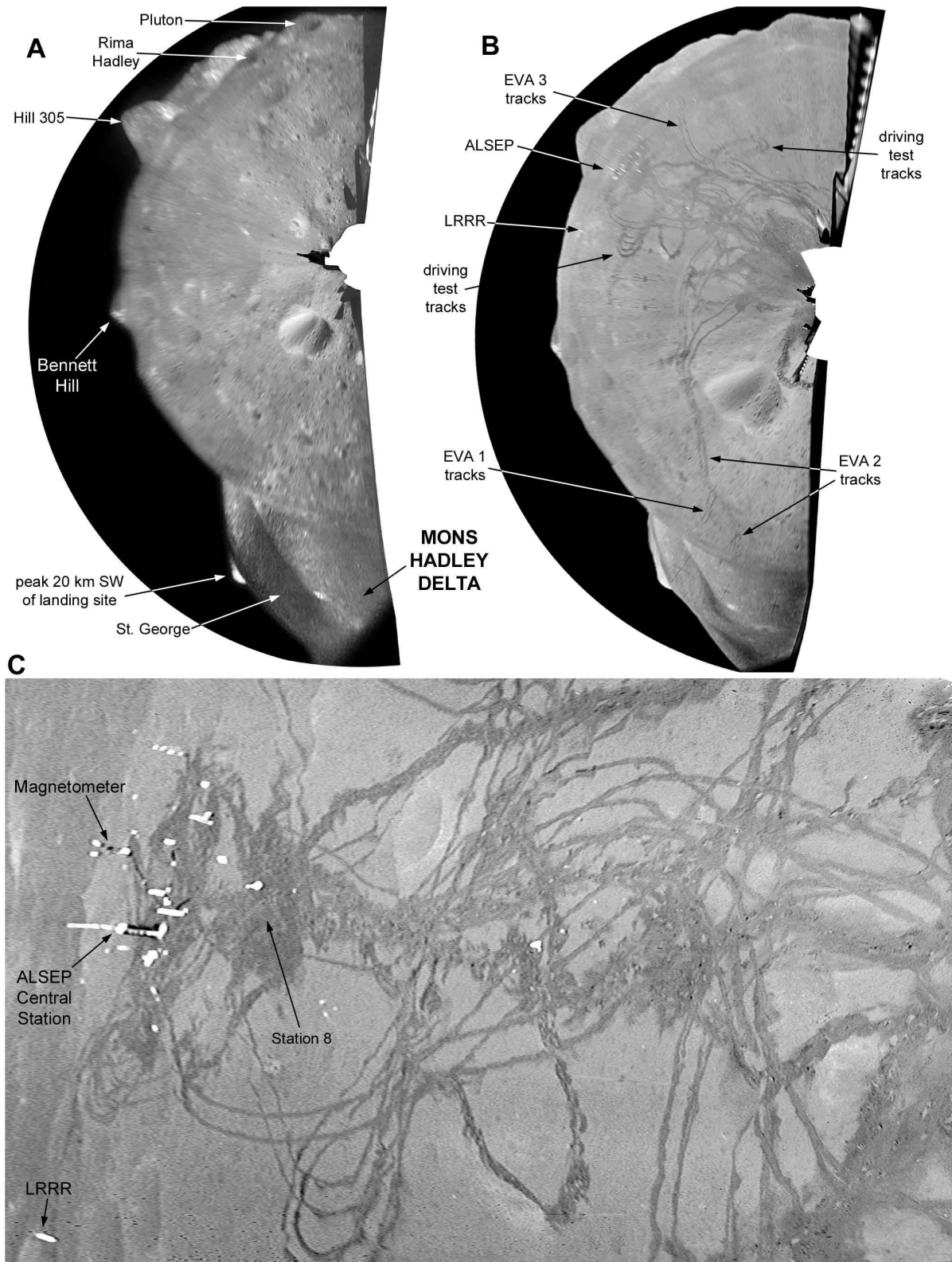


Figure 246. Apollo 15 reprojected panoramas. A: LM window panorama before EVA 1. B: LM Window panorama after EVA 3. C: Enlargement of image B showing tracks between the LM and ALSEP after EVA 3.

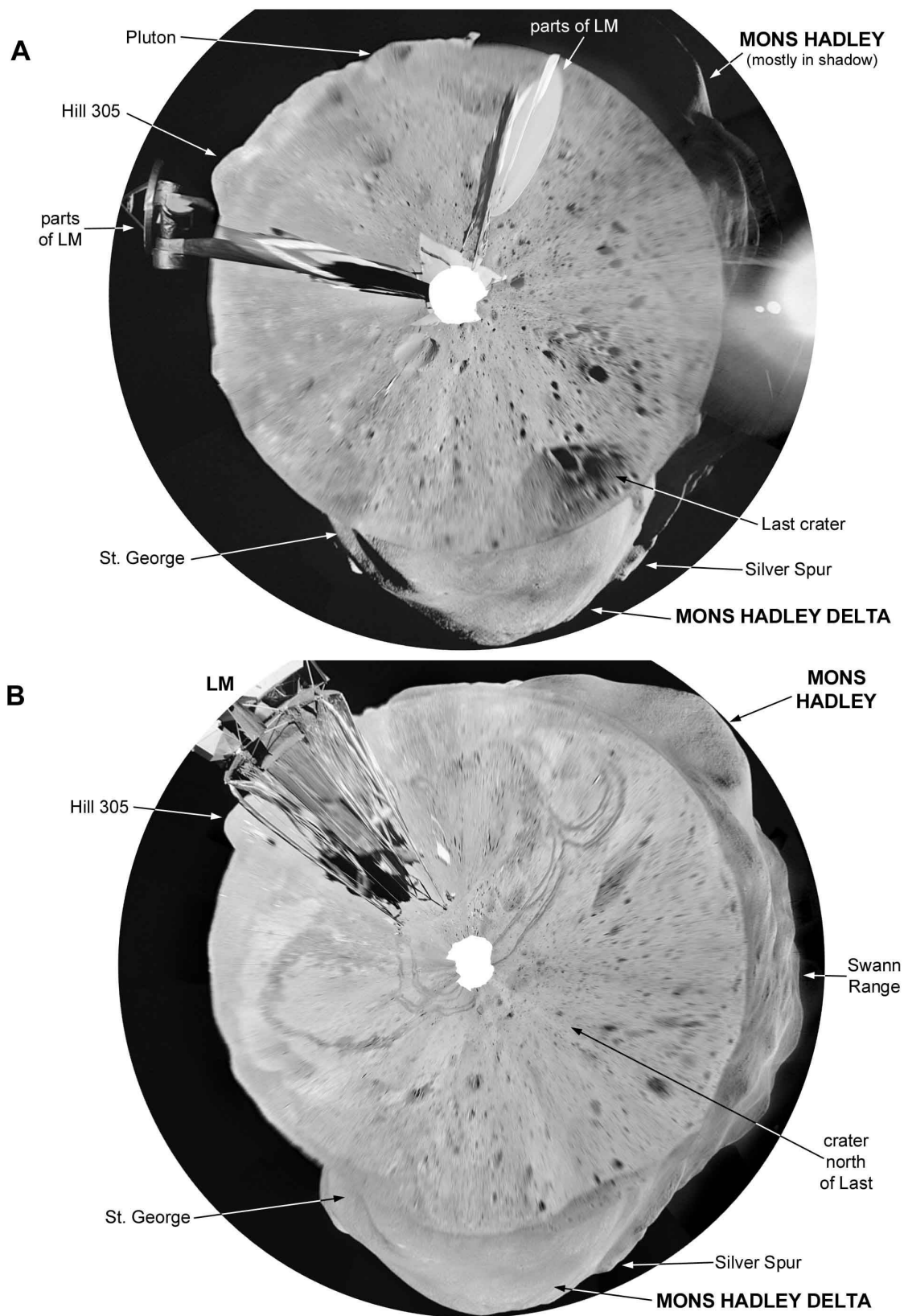


Figure 247. A: SEVA panorama taken just after landing. B: Panorama southeast of LM late in EVA 2.

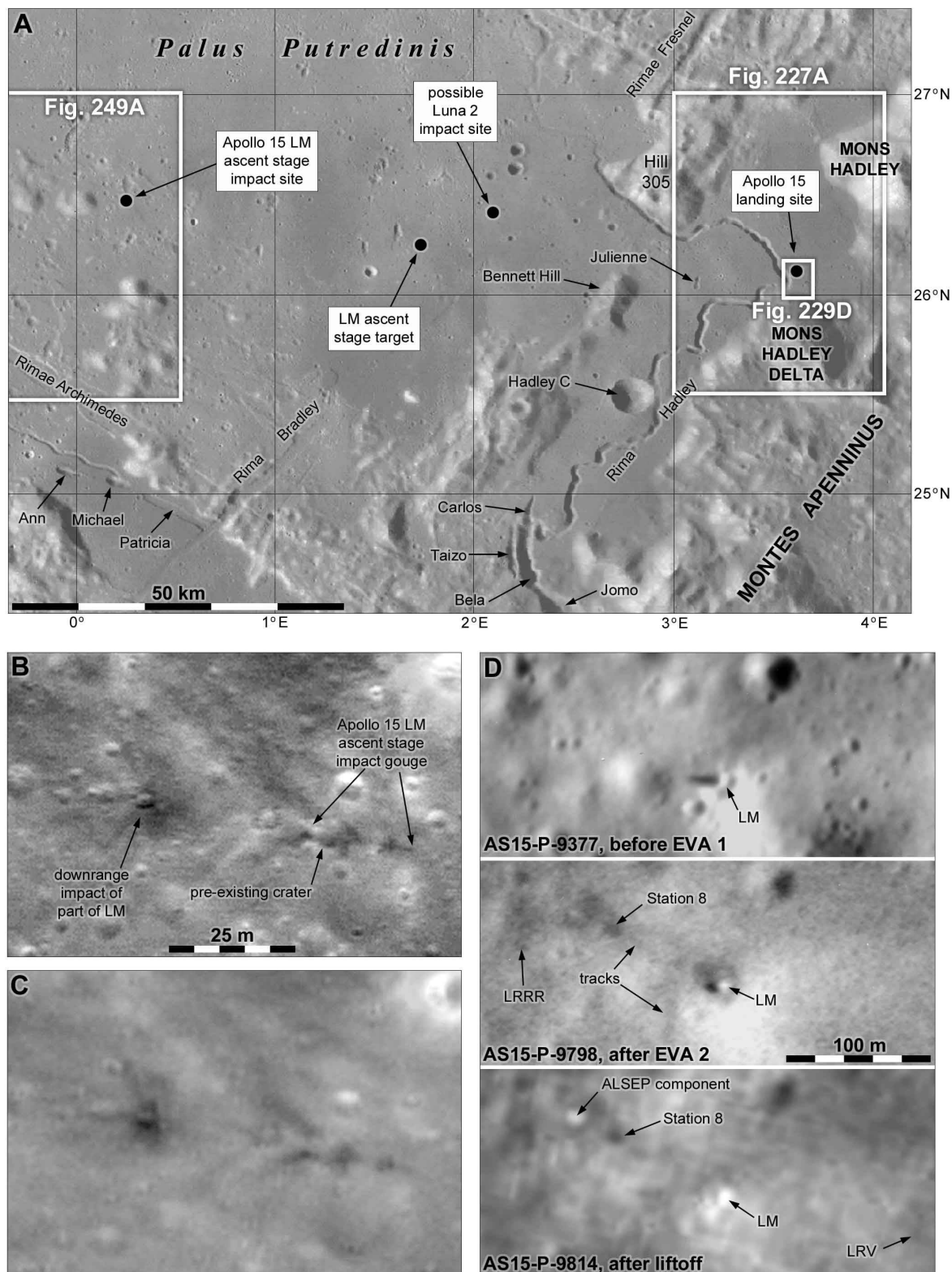


Figure 248. Apollo 15 Lunar Module ascent stage impact and walking EVA plan. A: Landing site and ascent stage target and impact locations. B: Ascent stage impact site in LRO image M109236068R. C: Impact site in LRO images M1144800863R and M1123598120L, merged to emphasize albedo. D: Apollo 15 panoramic camera images of the LM area. LRRR and LRV can only be located with hindsight.

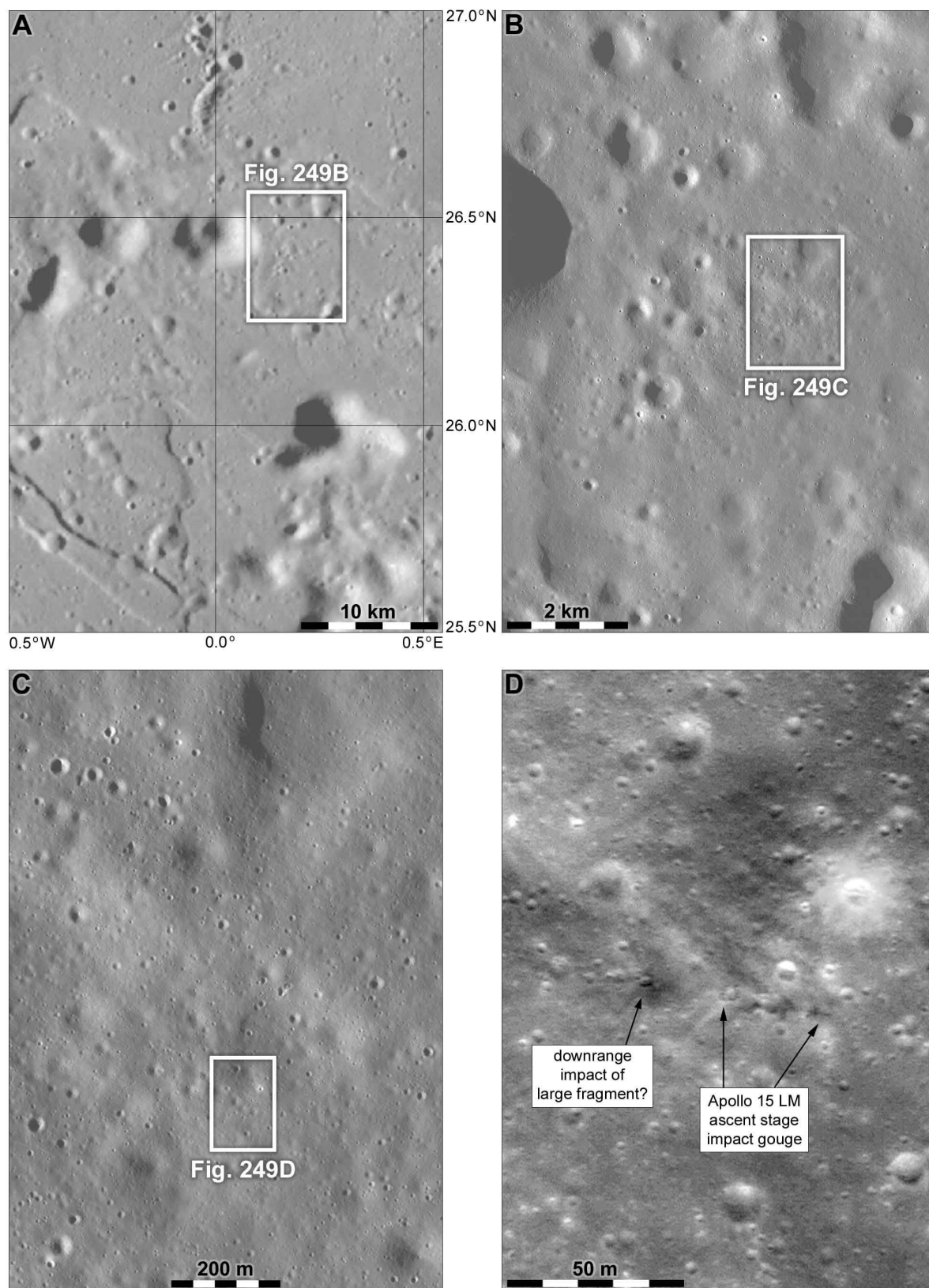


Figure 249. Apollo 15 LM ascent stage impact. B and C are parts of LRO image M1173058973L. D is part of LRO image M109236068R.

The Apollo 15 LM ascent stage was deliberately crashed to provide a seismic signal of known strength for the three active seismic stations now installed (Apollos 12, 14 and 15). The target point was at 26.25° N, 1.75° E, only about 10 km from the location of the possible observation of the Luna 2 impact dust cloud (Figure 10D in part 1 of the Chronicle). The actual impact point was tracked to 26.36° N, 0.25° E, about 40 km further west and 93 km from the landing site (NASA, 1971d; NASA, 1971e). The Apollo 15 Final Flight Plan placed the target at 26.25° N, 1.67° E, and just before the LMAS was deorbited the Public Affairs Officer at Apollo Mission Control gave the location as 26.2° N, 1.1° E (Apollo 15 Flight Journal, https://history.nasa.gov/afj/ap15fj/18tunnel_leak_lm_jett.html). Figure 229A shows the Palus Putredinis area with the LM ascent stage target and impact points and the Apollo 15 landing site. Ascent stage impact sites were difficult to find even in LRO images, but a linear structure with dark albedo markings at 26.406° N, 0.241° E (found independently by Michael Marcus and this author) is thought to mark the crash of the Apollo 15 ascent stage. It is shown in Figures 248B, 248C and 249.

Apollos 15 to 17 carried a set of remote sensing instruments in their Service Modules. The panoramic camera obtained over 1500 very high resolution panoramic images including stereoscopic coverage. The mapping camera provided high-quality metric photographs of the lunar surface and simultaneous star images to give accurate pointing information for a new generation of lunar maps. The other instruments and their results are described at the end of coverage of the Apollo missions. Several Apollo 15 panoramic camera images show the LM with its shadow shrinking as the sun rose higher (Figure 248D). Image 9798 also reveals a darkened strip between LM and ALSEP caused by multiple rover tracks and footprints. Features like the LRV and LRRR are barely detectable. These were only the second set of orbital images (after those of Surveyor 1) to show landed hardware on the lunar surface.

Like all orbital Apollo missions, Apollo 15 photographic coverage at high resolution lies under the CSM groundtrack, which gradually shifted westwards relative to the surface during the time spent in orbit. The SIM bay cameras photographed mostly areas directly under the spacecraft, but coverage was extended by images directed towards the horizon. The lower resolution images were taken from high altitude during the departure from the Moon and in this case cover mostly the nearside (Figure 250).

The 41kg Apollo 15 subsatellite PFS-1 measured magnetic fields and solar flares. It was a 1 m long spin-stabilized cylinder rotating at about 12 rpm with its spin axis roughly perpendicular to the ecliptic. Three 1.5 m booms around its base unfolded after deployment. It transmitted data for 6 months until most data channels failed in February 1972. The remaining channels were monitored intermittently until January 1973, when ground support ended. The subsatellite probably struck the lunar surface after a few years, as low lunar orbits are often unstable, but its impact point is not known.

Chaikin, A., 1994. *A Man on the Moon: The Voyages of the Apollo Astronauts*. New York: Viking Press. ISBN: 0-670-81446-6

Clarke, A. C., 1955. *Earthlight*. New York, N. Y.: Ballantine Books.

Collectspace.com, 2020. Profile: Apollo 15 "Sieger" covers.

http://www.collectspace.com/resources/profiles/profiles_a15sieger.html

Defense Mapping Agency (DMA), 1975. *Apollo 15 Traverses*. NASA Lunar Photomap 41B4S4(25), original scale 1:25 000, 2nd edition, April 1975. <https://www.lpi.usra.edu/resources/mapcatalog/LPST/41b4s4/150dpi.jpg>

Grott, M., Knollenberg, J. and Krause, C., 2010. Apollo lunar heat flow experiment revisited: a critical reassessment of the in situ thermal conductivity determination. *Journal of Geophysical Research: Planets*, 1 November 2010. DOI: 10.1029/2010JE003612.

Irwin, J. B. with Emerson, W. A., 1973. *To rule the night: the discovery voyage of astronaut Jim Irwin*. Philadelphia: A. J. Holman Co.

Langseth, M. G., Clark, S. P., Chute, J. L., Keihm, S. J. and Wechsler, A. E., 1972. The Apollo 15 lunar heat-flow measurement. *The Moon*, v. 1, no. 4, pp. 390-410.

Langseth, M. G., Keihm, S. J. and Peters, K., 1976. Revised lunar heat-flow values. *Proceedings of the 7th Lunar Science Conference. Geochimica et Cosmochimica Acta*, Supplement 7, pp. 3143-3171.

MSC, 1971a. *Apollo 15 final lunar surface procedures*, Manned Spacecraft Center (MSC), Houston, Texas, 9 July 1971. <https://www.nasa.gov/wp-content/uploads/static/history/alsj/a15/a15lsp.pdf>

MSC, 1971b. *Apollo 15 mission report*. Houston, Texas: Manned Spacecraft Center, December 1971. Report MSC-05161. <https://www.nasa.gov/wp-content/uploads/static/history/alsj/a15/ap15mr.pdf>

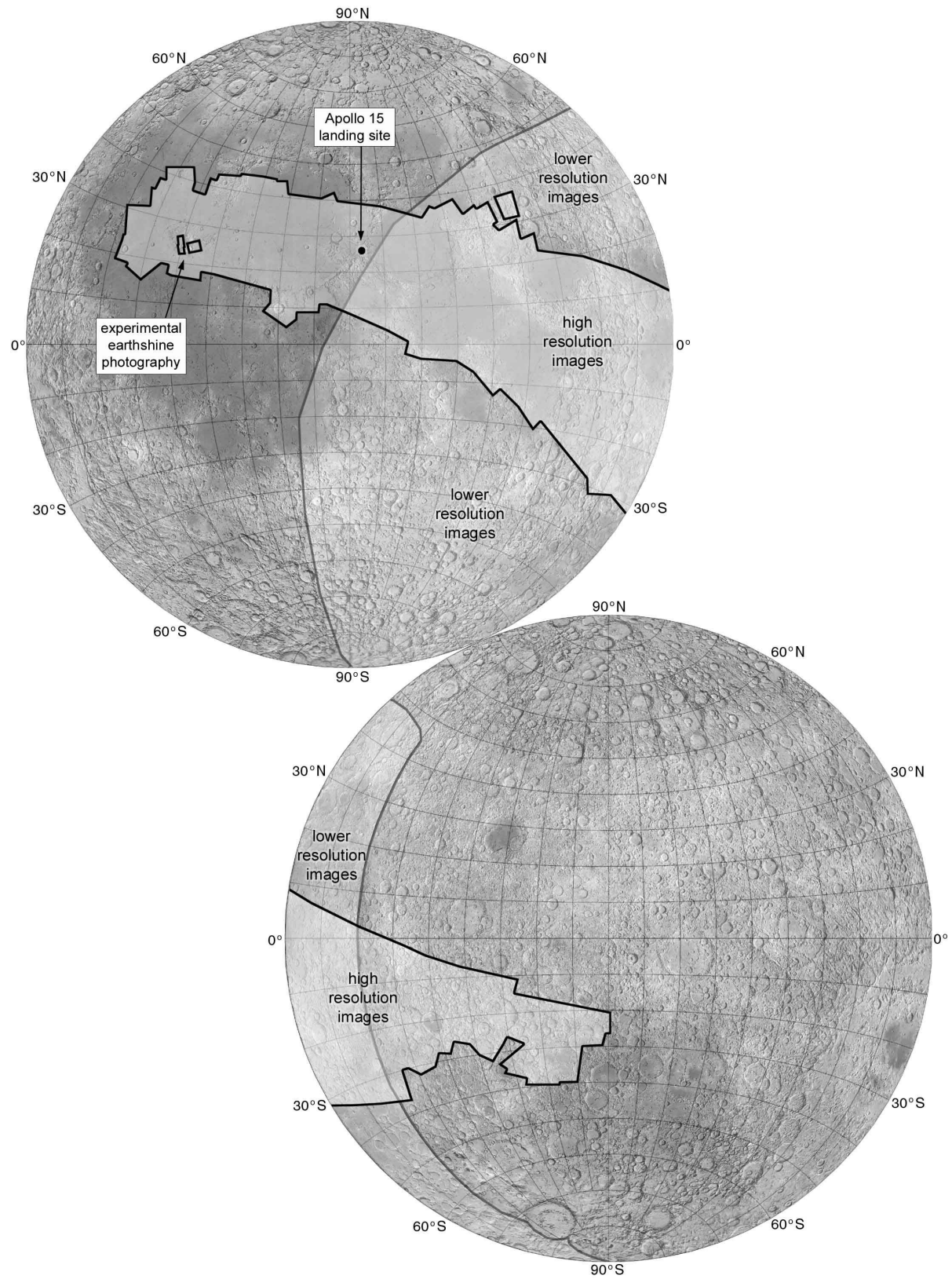


Figure 250. Apollo 15 photographic coverage.

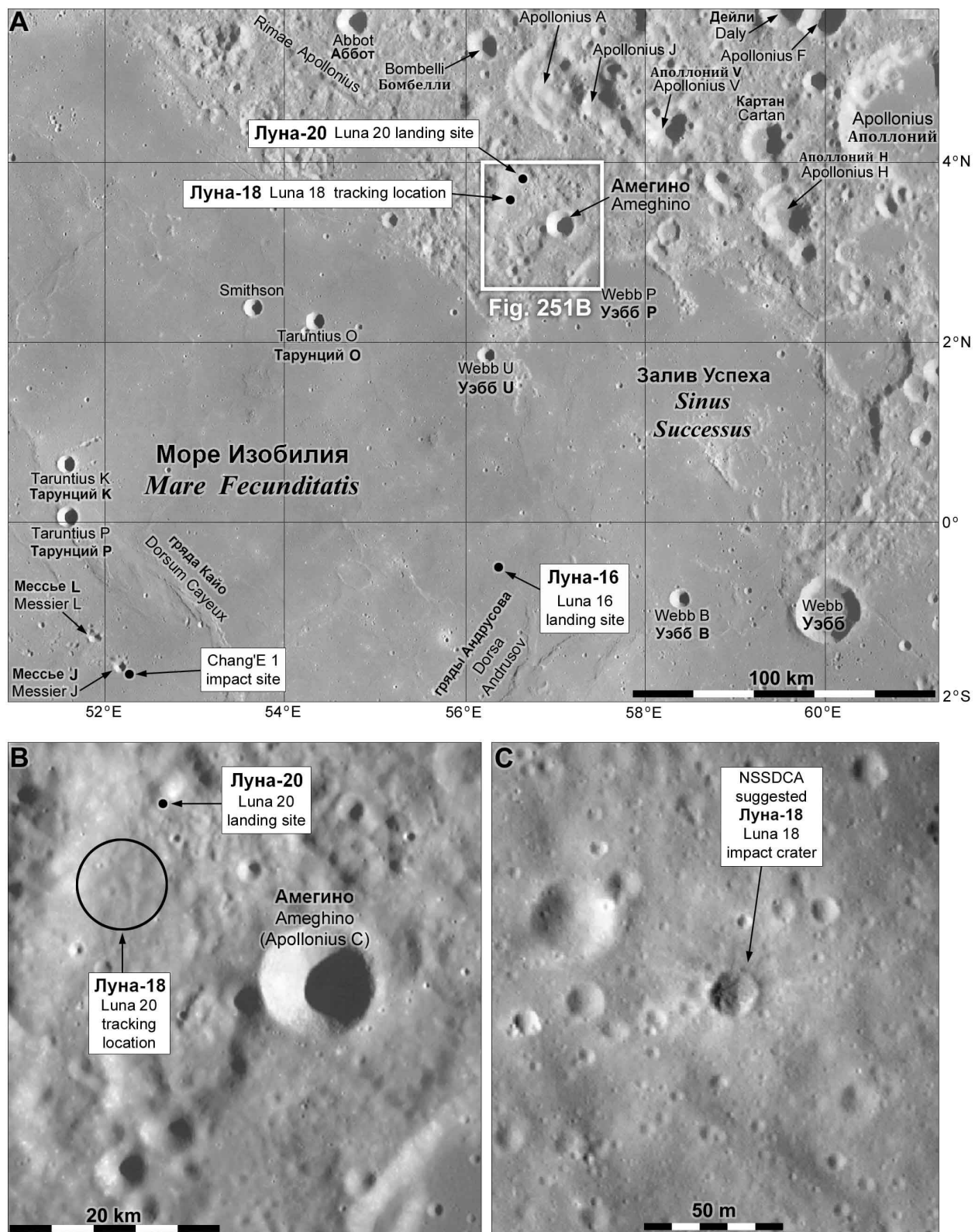
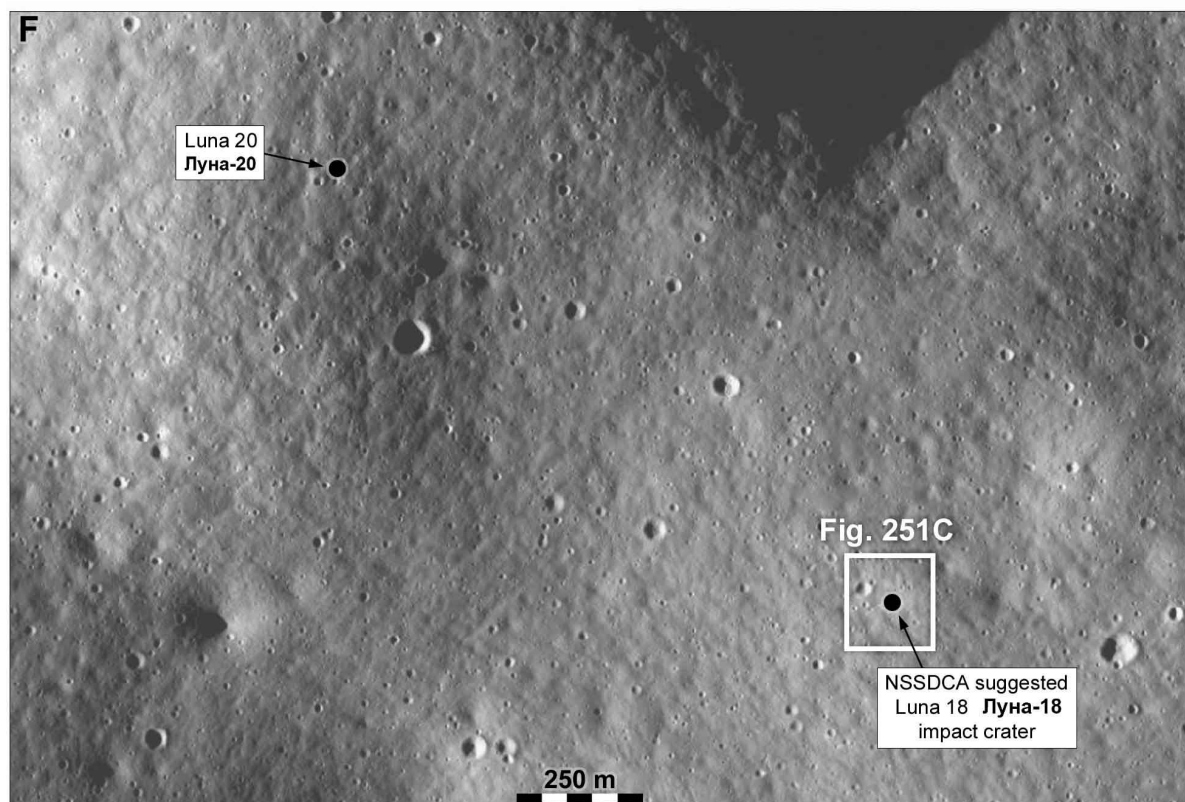
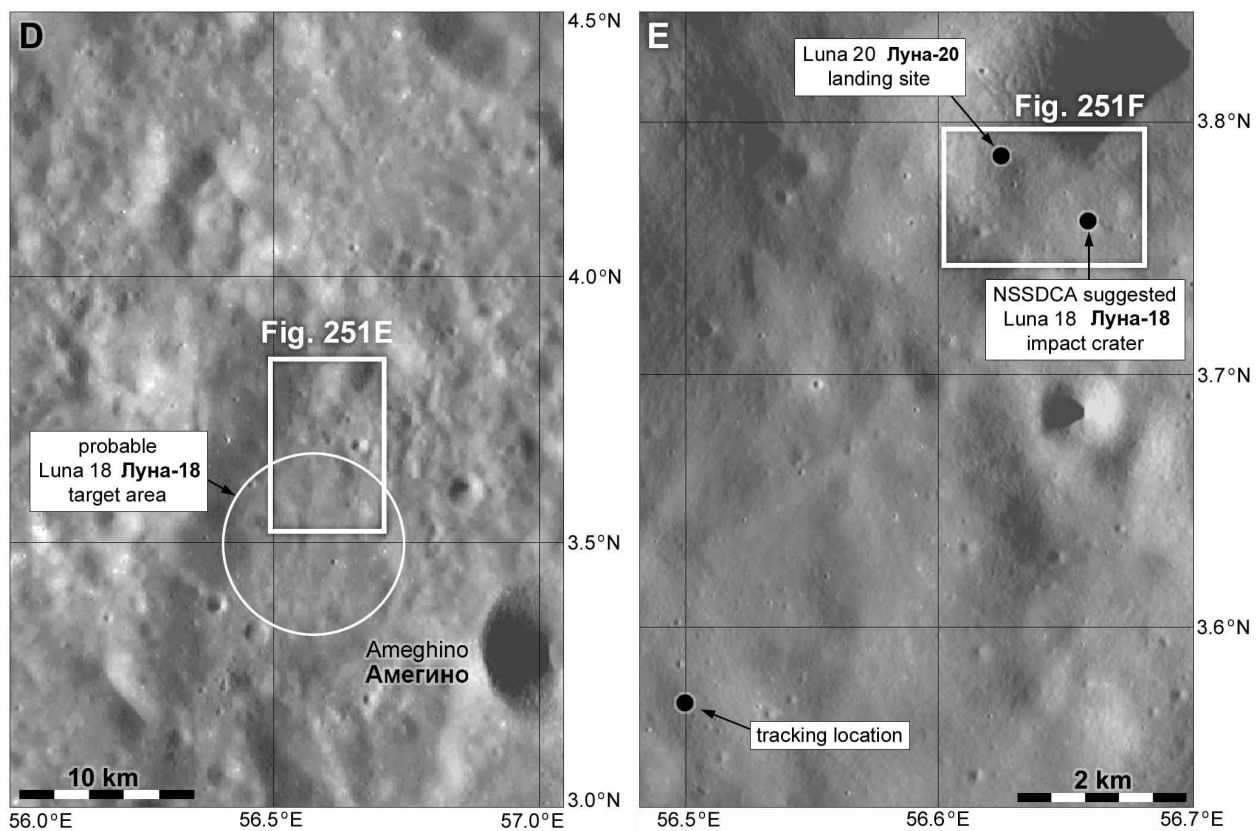


Figure 251 (both pages): Luna 18 impact area. A, B: context maps (LROC wide angle mosaics). C: crater suggested by NSSDCA as the Luna 18 impact site. D-F: suggested impact location, probably incorrect.



NASA, 1971a. Apollo 15 prelaunch mission operation report. NASA Office of Manned Space Flight, report M-933-71-15, 17 July 1971.

NASA. 1972. Apollo 15 Preliminary Science Report, NASA SP-289. Washington, D. C.: National Aeronautics and Space Administration. <https://www.nasa.gov/wp-content/uploads/static/history/alsj/a15/as15psr.pdf>

Saal, A.E., Hauri, E.H., Cascio, M.L. *et al.*, 2008. Volatile content of lunar volcanic glasses and the presence of water in the Moon's interior. *Nature*, v. 454, no. 7201, pp. 192-195. <https://doi.org/10.1038/nature07047>

Short, N. M., 1975. *Planetary Geology*. Englewood Cliffs, N. J.: Prentice-Hall, Inc.

Slayton, D. K. with Cassutt, M., 1994. *Deke! U.S. manned space from Mercury to the Shuttle*. New York: Forge Books. ISBN: 0312855036

Stooke, P. J., 2007. *The International Atlas of Lunar Exploration*. Cambridge: Cambridge University Press.

Stooke, P. J., 2018. Apollo 15 traverse mapping. Presented at the 49th Lunar and Planetary Science Conference, The Woodlands, Texas and online, 19-23 March 2018. Abstract no. 1007. <https://www.hou.usra.edu/meetings/lpsc2018/pdf/1007.pdf>

Swann, G. A. *et al.*, 1972. Preliminary geologic investigation of the Apollo 15 landing site. *Apollo 15 Preliminary Science Report*, NASA SP-289, pp. 5-1 to 5-112. Washington, D. C.: NASA.

Wagner, R. V., Nelson, D. M., Plescia, J. B. *et al.*, 2017. Coordinates of anthropogenic features on the Moon. *Icarus*, v. 283, pp. 92-103.

Wilhelms, D. E., 1987. *Geologic history of the Moon*. USGS Professional Paper 1348. Washington, D. C.: U. S. Government Printing Office.

Worden, A. and French, F., 2011. *Falling to Earth: an Apollo 15 astronaut's journey to the Moon*. Washington, DC: Smithsonian Books. ISBN-13: 978-1588343093



2 September 1971: Luna 18

Luna 18 was one of the Soviet Union's series of sample return missions. Luna 16 (Figures 176, 177) collected material from Mare Fecunditatis, and Luna 18 would attempt the same feat in a highland area about 120 km further north. The lander was essentially the same as Luna 16 but carried improved navigation systems. The designer, Georgy N. Babakin of the Lavochkin Design Bureau, died at the age of 57 on 3 August 1971, only a month before the launch.

Luna 18 was launched from Baikonur at 13:41 UT on 2 September 1971 into a parking orbit and was then placed on a lunar trajectory. The spacecraft made two corrections to its trajectory on 4 and 6 September and then entered a 100 km circular lunar orbit inclined 35° to the equator on 7 September. It made 54 orbits and several orbit adjustments before beginning its descent. The final orbit before descent was 18 by 100 km in altitude. Contact was lost at 07:48 UT, just before the expected landing time on 11 September. The website www.zarya.info, maintained by British space enthusiast Robert Christie, reported that the spacecraft landed on a steep slope or fell over, and no further communication was possible. Other accounts (Huntress and Marov, 2011) suggest the lander ran out of fuel before landing and crashed.

Tracking suggested that Luna 18 struck the surface in the highland region between Mare Fecunditatis and Mare Crisium, within a few km of 3.57° N, 56.50° E. This area lies in a broad valley northwest of the crater Apollonius C, later named Ameghino. Figure 251A depicts the Luna 16 and Luna 20 landing region on a mosaic of LRO wide angle images, and Figure 251B shows more detail of the expected landing area. No obvious sign of the lander has yet been found. If Luna 18 failed during the descent it might have made a small crater, but if it landed on a steep slope and overturned, it should remain as a recognizable object on the surface. Luna 23 also fell over as it landed, and it can be seen clearly in LROC images. Several small craters with unusual ejecta or dark spots occur in the region, but all can be found in Apollo 15 panoramic camera images AS15-P-9463 and AS15-P-9465 taken before the landing. The NSSDCA description of the mission repeated the above coordinates and noted that an LRO image shows a crater which might be the Luna 18 impact site at 3.76° N, 56.66° E, but it more closely resembles a natural hypervelocity impact (Figure 251C, 251G).

Soviet sample return missions were restricted to a narrow range of longitudes near 60° E, from which a vertical ascent at a little over lunar escape velocity automatically placed the vehicle on an Earth return trajectory. The site was sufficiently important that it was reused for Luna 20, five months later.

Data from Luna 18's continuous-wave radio altimeter determined the mean density and surface roughness of the lunar surface (Krupenko *et al.*, 1976). The Luna 18 area was rougher than the subsequent Luna 20 site. The altimeter was used only below 2 km altitude.

Huntress, W. T. and Marov, M. Ya., 2011. Soviet robots in the solar system. Mission technologies and discoveries. New York: Springer Praxis.

Krupenko, N.N., Ruzskii, E.G. and Cherkasov, V.V., 1976. Radar experiments aboard the automatic lunar stations. *Cosmic Research*, v. 14, pp. 410-411 (*Kosmicheskie Issledovaniya*, v. 14, no. 3, pp. 460-461, May-June 1976.)



28 September 1971: Luna 19

Luna 19, the first of a new class of heavy lunar orbiters, was launched at 10:00 UT on 28 September 1971. The orbiter was a modified version of the Lunokhod landing stage. After leaving its temporary Earth parking orbit and making two trajectory corrections on 29 September and 1 October, the 5600 kg spacecraft was placed in a 140 km, 2 hour circular lunar orbit inclined 40.58° to the equator on 3 October. Four days later the orbit was altered to 127 by 135 km. The onboard instruments were designed to study the near-lunar radiation environment, gamma-ray emissions from the lunar surface, the solar wind, and to photograph the surface with a novel camera system. Gravity studies were also conducted to help locate mascons (Figure 84C). A radar altimeter was intended to map the topography of the surface under the spacecraft, but it may not have done so.

Photography began by about 19 October, and in November the orbit was changed to 77 by 385 km to improve image resolution. Coverage in the area from 30° S to 60° S and 20° E to 80° E (or 20° E to 30° E, either a misprint or referring to a single image) has been reported, probably referring to only one orbit as other images fall outside this area (Figure 252F). It appears that only a few panoramic images were taken, but the extent of each panorama and the total coverage are not known as very little information has been released from the camera experiment. The altimeter was used to measure radar reflectivity at two locations just east of Rümker which were radar reflectivity targets (Krupenko *et al.*, 1975). The locations were 40° 50' N, 54° 45' W to 41° N, 54° W and 41° N, 54° W to 41° 10' N, 53° 20' W (Figure 253A). The altimeter may not have been used for altimetry. Stubbs *et al.* (2011) and Vyshlov *et al.* (1976) described a Luna 19 radio occultation experiment made on 11 June 1972 with the occultation tangent to the lunar surface at 40° S, 96.3° E (Figure 253B). This is just on the farside and suggests a favourable libration at that time. The observation was used to study plasma above the lunar surface. Vasil'ev *et al.* (1974) noted that this was just one of a series of occultations, three on 8 May at 30-31° N, 80.1-80.3° E, one on 14 May at 36.9° N, 97.0° E and three on 11 June at 40° S, 96.2-96.4° E (Fig. 252).

The camera was a unique scanning system which scanned a line from horizon to horizon under the spacecraft, each successive scan line being displaced along the ground track by the spacecraft's orbital motion. Each panoramic image could have extended from terminator to terminator, though the actual extent is not known and only small sections have been released. The original images are of reasonable quality, though the apparent resolution of at best 100 m would not have been sufficient to plan human landings. The camera and possibly some of the other instruments such as the altimeter were regarded as experimental, and the results seem to have been treated as engineering rather than scientific data with very limited published analysis. The likely explanation is that the spacecraft was testing instruments for use on future planetary flyby and orbital missions.

Several Luna 19 images are shown in their original and reprojected formats in Figure 252. Figures 252A and 252C show the original image format and a map-projected view of the Metius region near 40° S, 45° E. The scanner viewed the surface from horizon to horizon, but near the horizons the view is too oblique to be useful. The large crater at centre is Metius.

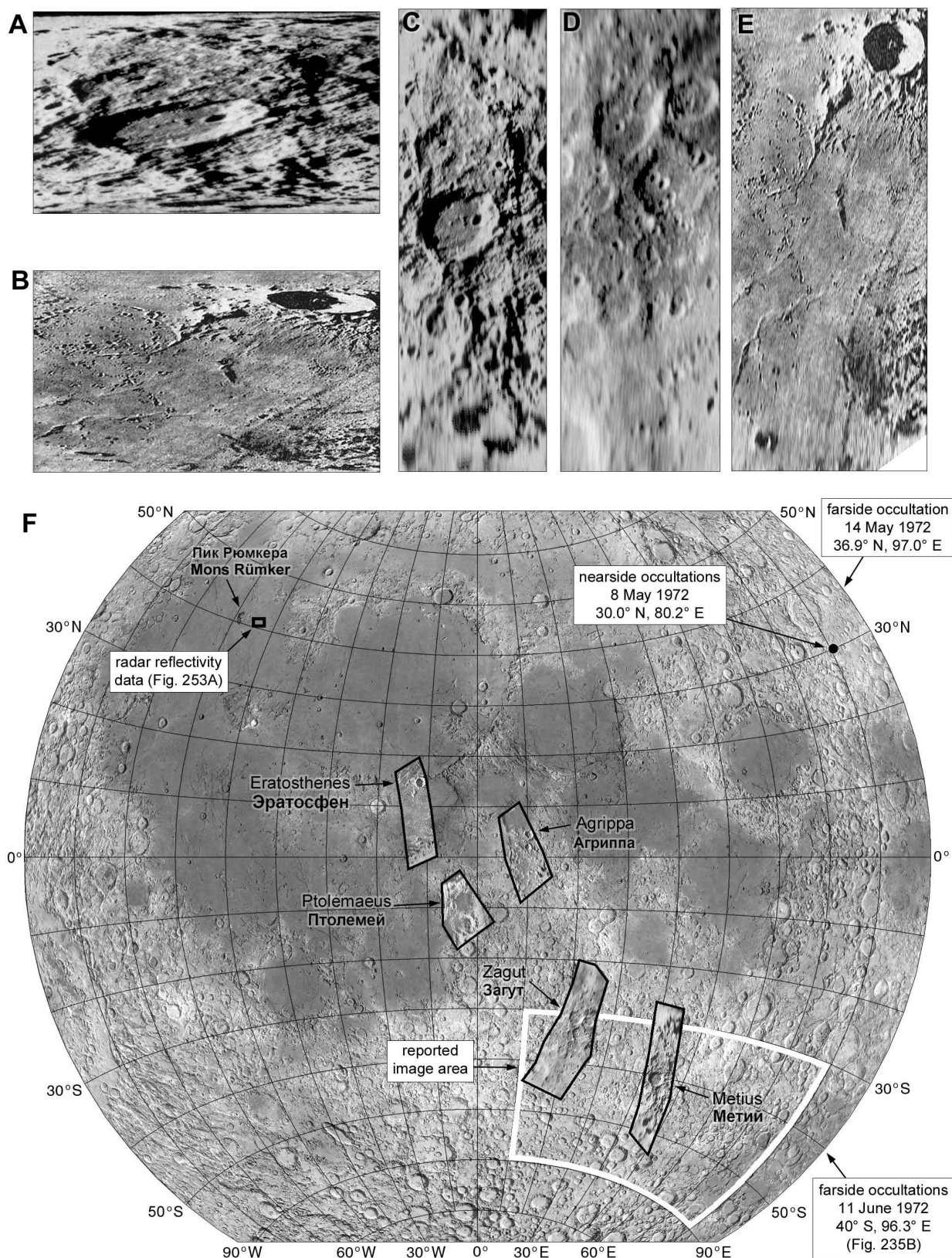


Figure 252. Luna 19 images. A, B: images of Metius and Eratosthenes in their original format. C, D, E: roughly reprojected images of Metius, Zagut and Eratosthenes. F: locations of images and other observations.

Figures 252B and 252E show Eratosthenes, Stadius and Sinus Aestuum near 10° N, 12° W. The higher quality of the image may indicate it was taken during November after the orbit was lowered. Figure 252D is a map-projected fragment of an image of the craters Zagut, Lindenau and Rabbi Levi near 35° S, 22° E. Images were provided courtesy of MIIGAIK, with reprojections by P. Stooke. The location of other observations and the area said to have been the focus of Luna 19 imaging (white outline) are shown in Figure 252F. Five images, the only ones known to the author, are plotted in Figure 234F with black outlines. Other images may exist, and the images shown may be only small sections from longer panoramic image strips.

Luna 19's camera appears to have been the first purely electronic imaging system used in lunar orbit. Luna 12, the Lunar Orbiter spacecraft and the Apollo missions all used film cameras. Luna 19 operated for nearly 13 months and over 4000 orbits. It probably struck the surface as its orbit evolved under the influence of mascons, but its impact site is unknown.

Krupenko, N. N., Balo, A. G., Ruzskii, E. G. *et al.*, 1975. Results of radar experiments performed aboard the Luna 19 and 20 automatic stations. *Space Research XV. Proceedings of Open Meetings of Working Groups on Physical Sciences of the Seventeenth Plenary Meeting of COSPAR*, São Paulo, Brazil, June 1974. Edited by M. J. Rycroft. Berlin, Boston: De Gruyter, 1975, pp. 617-620. <https://doi.org/10.1515/9783112482124-082>

Stubbs, T. J., Glenar, D. A., Farrell, W. M. *et al.*, 2011. On the role of dust in the lunar ionosphere, *Planetary and Space Science*, v. 59, pp. 1659-1664. <https://doi.org/10.1016/j.pss.2011.05.011>

Vasil'ev, M. B., Vinogradov, V. A., Kolosov, M. A. *et al.*, 1974. Radio transparency of circumlunar space using the Luna-19 station. *Cosmic Research*, v. 12, pp. 102-107, July 1974 (*Kosmicheskie Issledovaniya*, v. 12, no. 1, pp. 115-121, January-February 1974)

Vyshlov, A.S., Savich, N.A., Vasilyev, M.B. *et al.*, 1976. Some results of cislunar plasma research. In Ness, N. F. (ed.), 1976. *Solar-wind Interaction with the Planets Mercury, Venus, and Mars: The Proceedings of a Bilateral Seminar of the US-USSR Joint Working Group on Near-Earth Space, the Moon, and Planets, Held at the Space Research Institute of the Academy of Sciences of the USSR, Moscow, 17-21 November 1975*. NASA SP-397.



1971: Science Working Panel

The Panel met on 11 to 12 May, 1 to 2 June, 3 August, 1 October, 15 to 16 November and 20 December 1971 to consider Apollo 16 activities. The Apollo 16 site at Descartes (Figure 253C) lay on the boundary between an area of undulating plains (Cayley Formation) and a region of hills extending northwards from Descartes crater (Descartes Formation). Two young ray craters would provide subsurface samples. Both the hills and the plains between them were thought to consist of highland volcanic materials, which was the chief reason for choosing this site. Later, during the mission itself, they were shown to be deposits of Imbrium basin ejecta.

Prior to this detailed planning in 1971 an alternative site had been suggested 10 km east of the 'field of activity', which at the time was centred on the northern rayed crater (Figure 254A). Dan Milton of the USGS office at Menlo Park, south of San Francisco, believed the eastern site would offer more reliable sampling of the hilly unit and suggested it to Dick Eggleton of USGS Flagstaff in a note dated 6/1/70 (taken to be 1 June 1970, just before a SWP meeting on this topic) in the archives at Flagstaff.

Several alternative versions of the Apollo 16 EVA traverses are illustrated in Figures 254B-E as they appeared in the minutes of the Panel meetings. A walking mission option was included. All EVAs using the LRV include visits to the hills north and south of the landing site (referred to as 'North Hills' and 'South Hills' at the May meeting but subsequently named 'Smoky Mountains' and 'Stone Mountain' respectively). The earliest plan (Figure 254B) did not involve climbing far up Stone Mountain but would drive a considerable distance along its base instead. The walking EVA (Figure 254F) could only reach Stone Mountain. It would only be followed if the LRV suffered a failure and could not be used. Figure 254E was the option eventually chosen for the Apollo 16 mission.

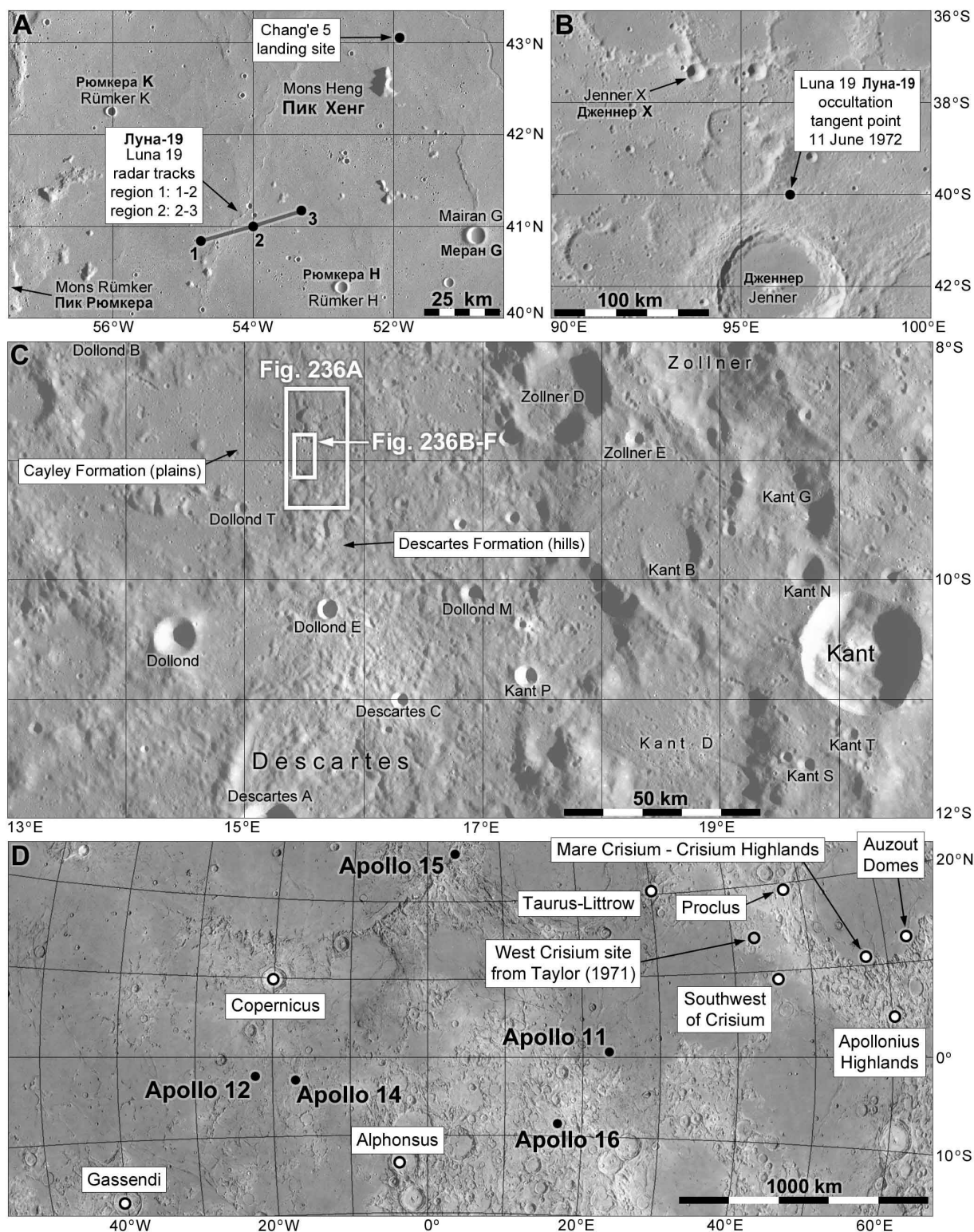


Figure 253. Luna 19 results, Apollo planning. A: Luna 19 radar reflectivity tracks. B: Luna 19 occultation point. C: Apollo 16 landing region with location of Figure 236. D: Locations of sites considered for Apollo 17 at the last ASSB meeting, and the West Crisium site considered by Taylor (1971).



11 February 1972: Apollo Site Selection Board

This, the last meeting of the Apollo Site Selection Board, selected the final Apollo Program landing site for the Apollo 17 mission. Consideration began in October to allow time for detailed assessments of many candidate sites. The objective was to find a site incorporating different types of material, especially pre-Imbrian material in highlands as far as possible from the Imbrium basin, and relatively young volcanic materials. The site should also allow orbital remote sensing in new areas of the Moon and be complex and interesting enough for the geophysical instruments to give good results.

Apollo 15 images were scrutinized as soon as possible in case an interesting new site could be found, in addition to those already considered. Six new areas were examined (Figure 253D), but three of them were too far east to allow adequate pre-landing tracking. Proclus, at 19° 30' N, 48° 30' E, about 100 km north of the crater itself, was too close to the edge of the accessible area. The remaining two were 'Southwest of Crisium' and Taurus-Littrow, a site in a mare-filled highland valley 70 km southeast of the old Littrow landing site candidate (Figures 113, 119, 120, 138). Taylor (1971) mentioned an additional site considered for Apollo 17. It was West Crisium, at 14.0° N, 43.0° E, north of the SW Crisium site. This site and another in Gassendi at 17.3° S, 40.5° W, were studied by Taylor to assess their feasibility. West Crisium was ruled out because fuel reserves were inadequate, especially if the Lunar Module had to be used in a rescue mode. Gassendi was found to be acceptable.

The three candidates considered previously were Alphonsus, Copernicus Central Peaks and Gassendi Central Peaks. EVA plans were compiled for these three sites and for Taurus-Littrow. Marius Hills also appeared on some of the planning documents but was outside the accessible area in the expected launch period. Copernicus was less appealing now because its ejecta had apparently been sampled by Apollo 12.

The whole Crisium region was now considered less important for Apollo because it fell within the area accessible to Soviet robotic sampling missions. Luna 18 had recently failed in an attempt to collect a sample from the Apollonius area but success was anticipated in the near future, and in fact came only two weeks after this meeting with Luna 20. Gassendi offered no young volcanic materials.

Areas potentially covered by the metric and panoramic cameras on Apollo 17 (excluding high oblique coverage) are shown in Figure 255A for three possible landing sites, Alphonsus, Gassendi and Taurus-Littrow. Gassendi offered the best new coverage as it allowed imaging of parts of the Orientale basin, but the overlap between Apollo 15 and Taurus-Littrow coverage was also desirable because it would allow comparisons between data from the different SIM bay instruments carried by Apollos 15 and 17.

Figure 255B shows the proposed landing area in Alphonsus and the nearby Ranger 9 site. Figure 255C shows the suggested landing site at 13° S, 4° W and EVA routes around it, from the ASSB minutes and NASA presentation graphic S-72-095-V. Dashed outlines are the prime sample collection areas. Figure 255D shows the proposed landing area at Gassendi, just west of the main central peaks and south of a smaller peak. The proposed Apollo 17 landing site was at 17° S, 40° W, and an alternative landing site might be placed west of the north-south trending rille. The EVA routes (somewhat uncertain because of the quality of the data sources) are taken from ASSB minutes and NASA presentation graphic S-72-096-V. Dashed outlines are the prime sample collection areas.

Taurus-Littrow was eventually selected for Apollo 17. It included highlands and apparently small volcanic cinder cones, though in the end the target was not placed close to the most obvious cinder cones (Figure 256A). Crucially, however, a dark spot on a landslide deposit (a crater now called Shorty) was interpreted as one of these cinder cones. None of these putative cinder cones would now (after LRO images became available) be interpreted as anything but ordinary impact craters, Taurus-Littrow also had the best options for the maximum 3.5 km radius walking EVAs if the LRV failed (Gassendi did not offer good walking options and Alphonsus was barely acceptable).

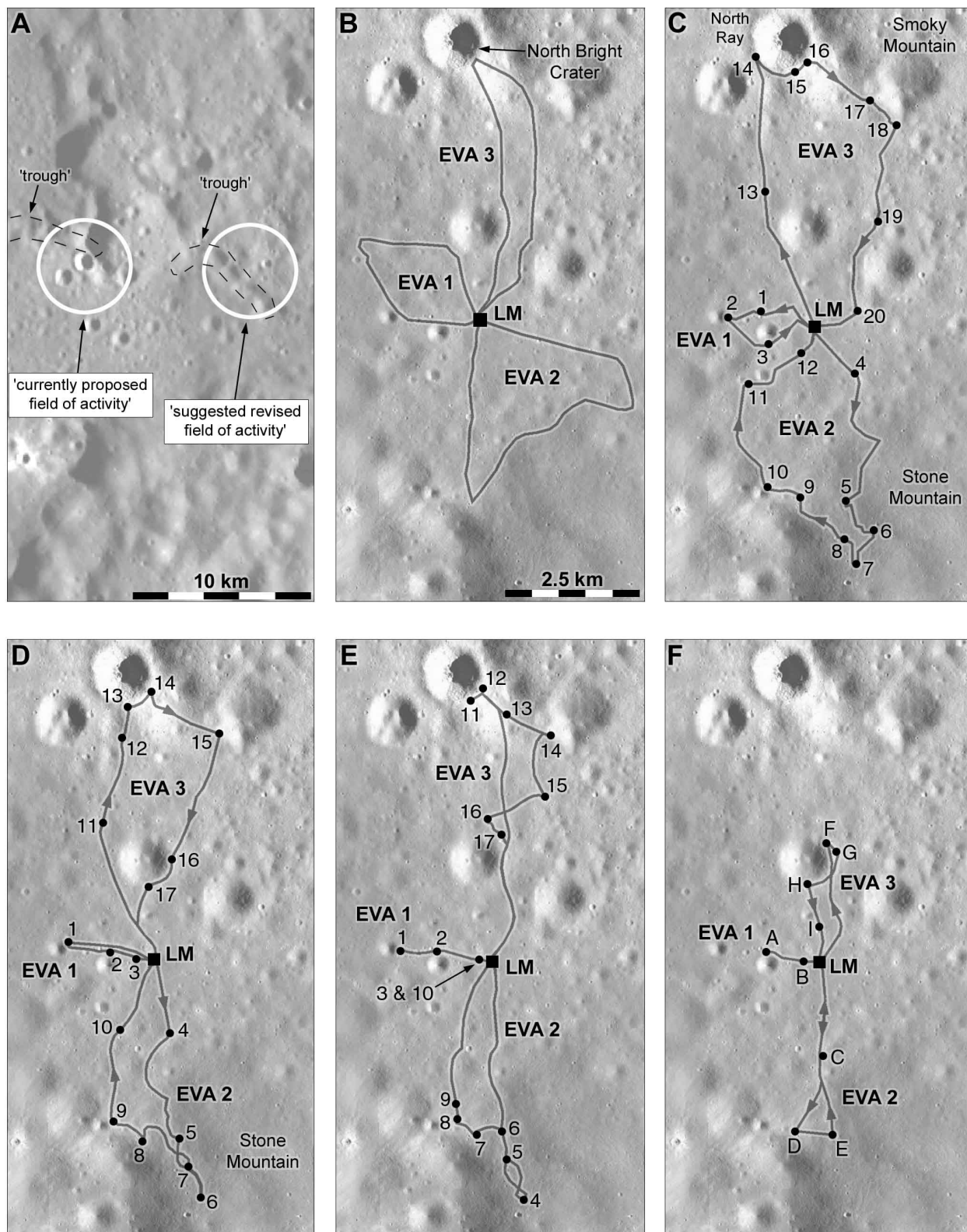


Figure 254. Evolving plans for the Apollo 16 EVAs. A: alternative site location. B-E: EVA plans with LRV. F: walking EVAs.

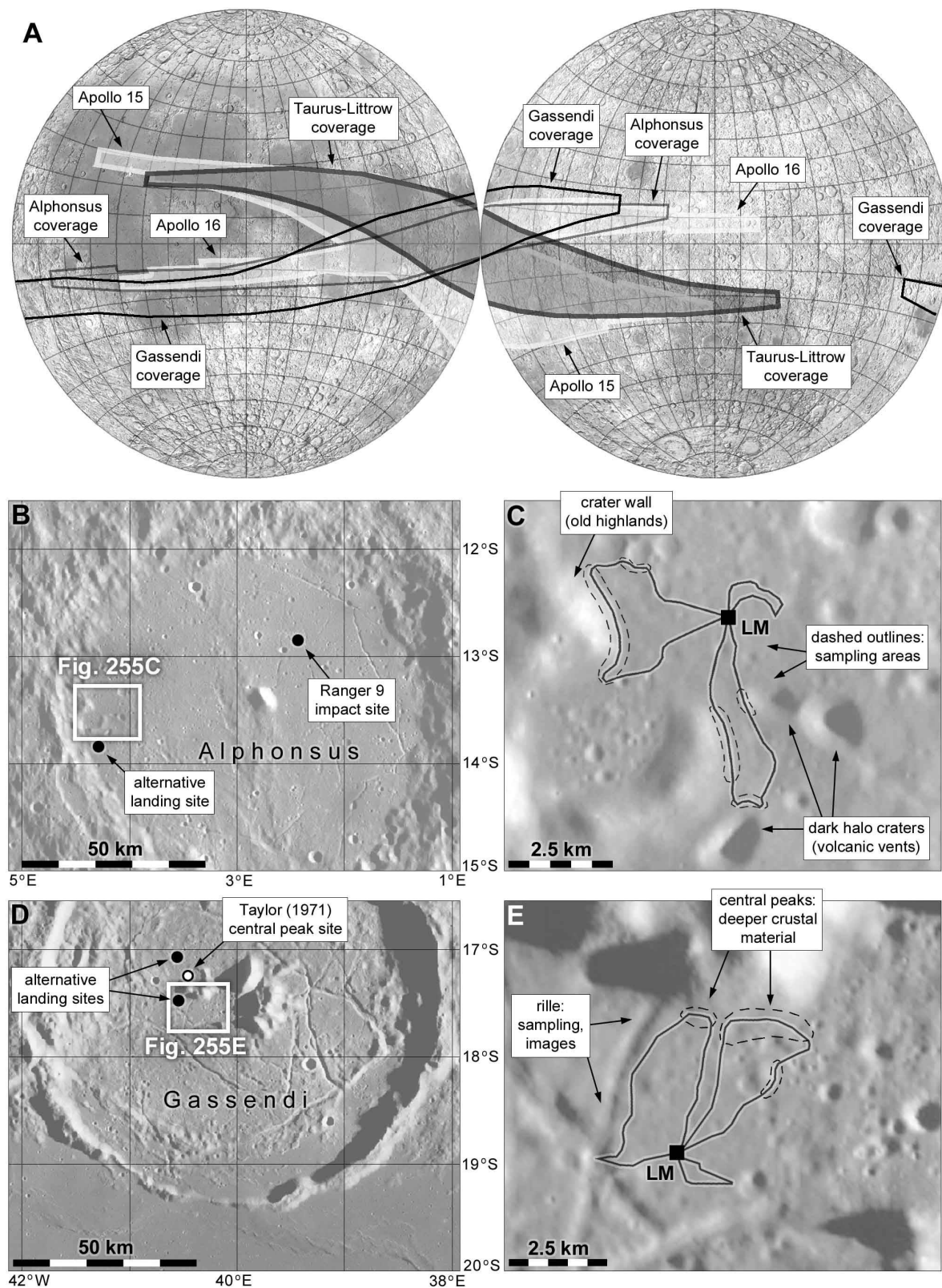


Figure 255. Apollo 17 site selection planning. A: coverage by the Metric and Panoramic Cameras for Apollo 15, Apollo 16 (anticipated) and the three candidate Apollo 17 sites. B, C: Alphonseus site and EVAs. D, E: Gassendi site and EVAs.

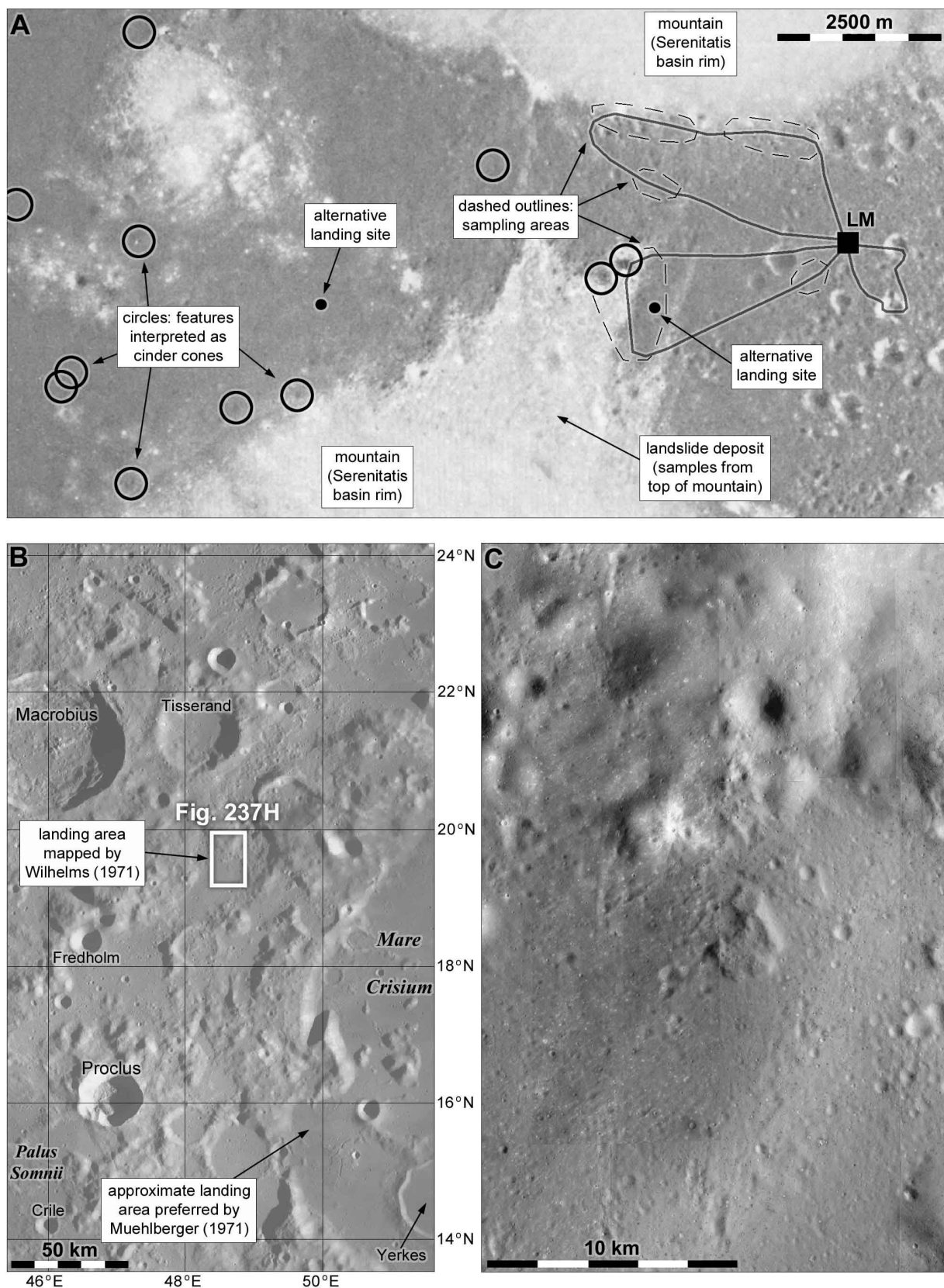


Figure 256. Apollo 17 site considerations. A: Taurus-Littrow site showing putative cinder cones. B, C: Proclus site.

Taurus-Littrow's narrow valley at first seemed too small to contain a full-sized landing ellipse, but growing experience suggested the constraints could be loosened and it became acceptable. The central part of the Taurus-Littrow valley is shown in Figure 256A with the proposed Apollo 17 landing site and two alternative landing locations. The region is located near 20° N, 30° E. EVA routes are taken from ASSB minutes and NASA graphic S-71-3532-V. The circles indicate dark halo craters (putative cinder cones) mapped by El-Baz (1972). Dashed outlines are the prime sample collection areas. The image is part of Apollo 15 panoramic camera frame 9554, illustrating the materials available for planning at the time.

Another site at Proclus crater was mapped by Lucchitta (1972) using Apollo 15 stereoscopic panoramic camera images (Figure 257B, C). The site was originally considered for Apollo because it offered ancient highlands (Crisium basin rim materials) with only limited contamination from Imbrium ejecta, smooth plains on the floor of a depression, and possible dark halo craters which might have been signs of younger volcanism. Mapping by Wilhelms (1971) suggested that the plains were rougher than anticipated, the area was mantled by ejecta from the Copernican crater Proclus, and the dark halo craters were likely to be impact craters excavating a darker subsurface layer. Ancient materials might be found at many sites, so Proclus was no longer considered a high priority site. Muehlberger (1971) preferred a site on the Crisium plains within reach of the basin rim massifs (Figure 257B) but it was outside the operational limits of the mission.

El-Baz, F., 1972. The cinder field of the Taurus mountains. *Apollo 15 preliminary science report*, NASA SP-289. Washington, DC: National Aeronautics and Space Administration, pp. 25-66 to 25-71.

Lucchitta, B. K., 1972. Geologic sketch map of the candidate Proclus Apollo landing site. *Apollo 15 preliminary science report*, NASA SP-289. Washington, DC: National Aeronautics and Space Administration, pp. 25-76 to 25-80.

Muehlberger, W. R., 1971. Apollo field geology investigations (S-059) experiment group recommendations for Apollo 17 landing sites. Memorandum to Noel Hinners, chair, ad hoc Site Selection Group, Apollo 17, 30 November 1971.

Taylor, G. S., 1971. SPS AV Reserves for an Apollo 17 Mission to West Crisium or Gassendi, Case 310. Bellcomm memorandum B71-12019, 28 December 1971.

Wilhelms, D. E., 1972. Preliminary geologic map of the region around the candidate Proclus Apollo landing site. . *Apollo 15 preliminary science report*, NASA SP-289. Washington, DC: National Aeronautics and Space Administration, pp. 25-72 to 25-75.



14 February 1972: Luna 20

The 5600 kg Luna 20 spacecraft was launched from Baikonur at 03:28 UT on 14 February 1972, placed in a low Earth parking orbit and then put on its lunar trajectory. After one trajectory correction it entered a 100 km circular lunar orbit inclined 65° to the equator on 18 February, and on the next day the orbital low point was reduced to 21 km. At 19:19 UT on 21 February Luna 20 landed safely in the hilly region between Mare Crisium and Mare Fecunditatis, in the same area targeted by the Luna 18 mission (Figure 251). Its final descent commenced 760 m above the surface, 160 m higher than for Luna 18.

The coordinates were given as 3.53° N, 56.55° E, reported to be only 1800 m southeast of the Luna 18 crash site, though the uncertainties in each point are at least several kilometres larger than this, and Luna 20 was eventually located in LRO images at 3.787° N, 56.625° E. The landing site was 120 km north of the Luna 16 site (Figure 251A). The lander's twin cameras surveyed the scene in tilted panoramas, extending from horizon to horizon with a stereoscopic view of the foreground. Several fragments of these panoramas have been published, enough to construct a nearly complete panorama (Figure 259). In Stooke (2007) some parts were reversed left to right after a misinterpretation of the image geometry. The images were supposed to allow the sample drill to be moved sideways to avoid rocks, but no significant rocks were visible in the drilling area.

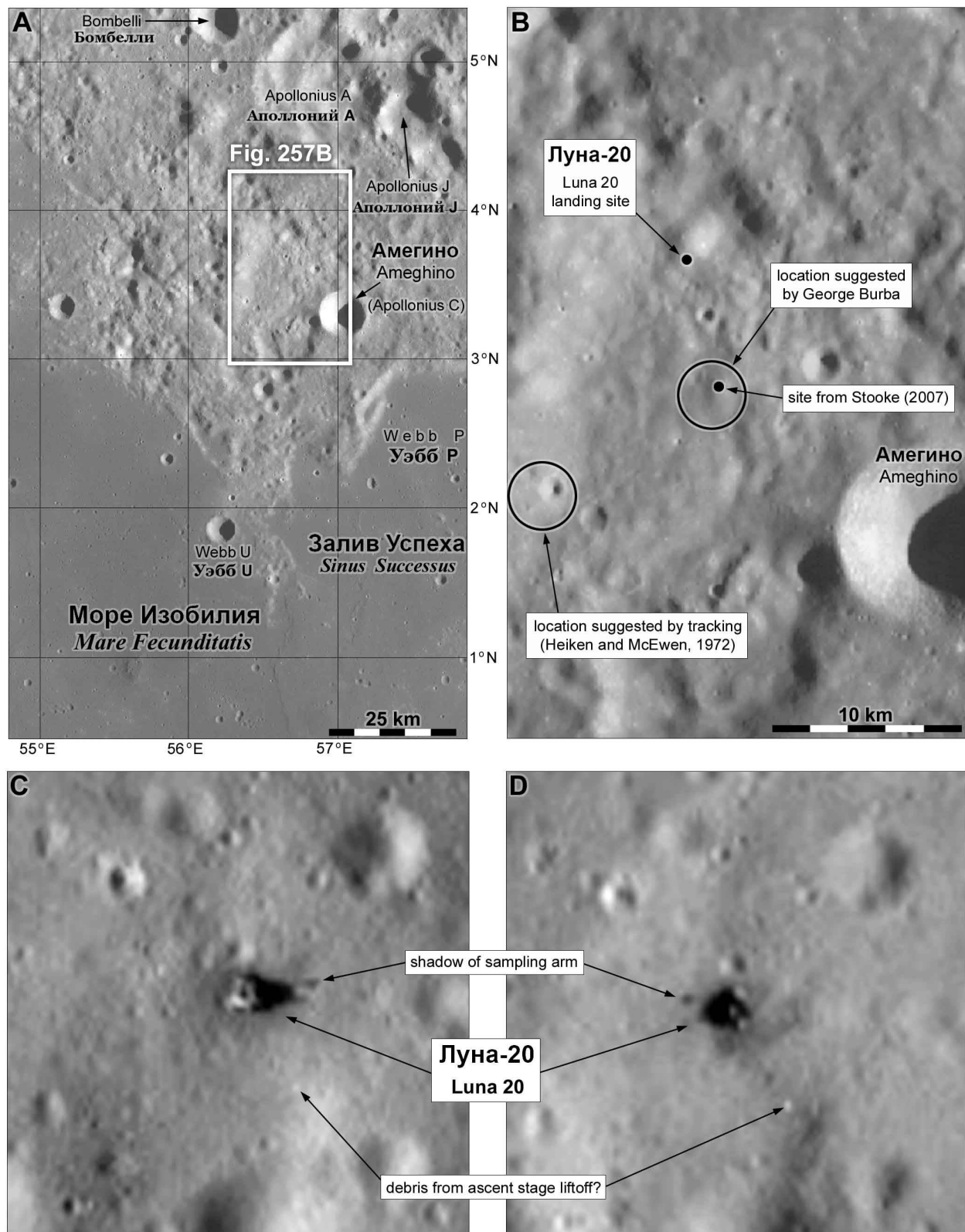


Figure 257. Luna 20 landing site. A: landing site region. B: Attempts to locate the landing site. C, D: Luna 20 imaged by LRO (C: image M119482862R. D: image M177264491R).

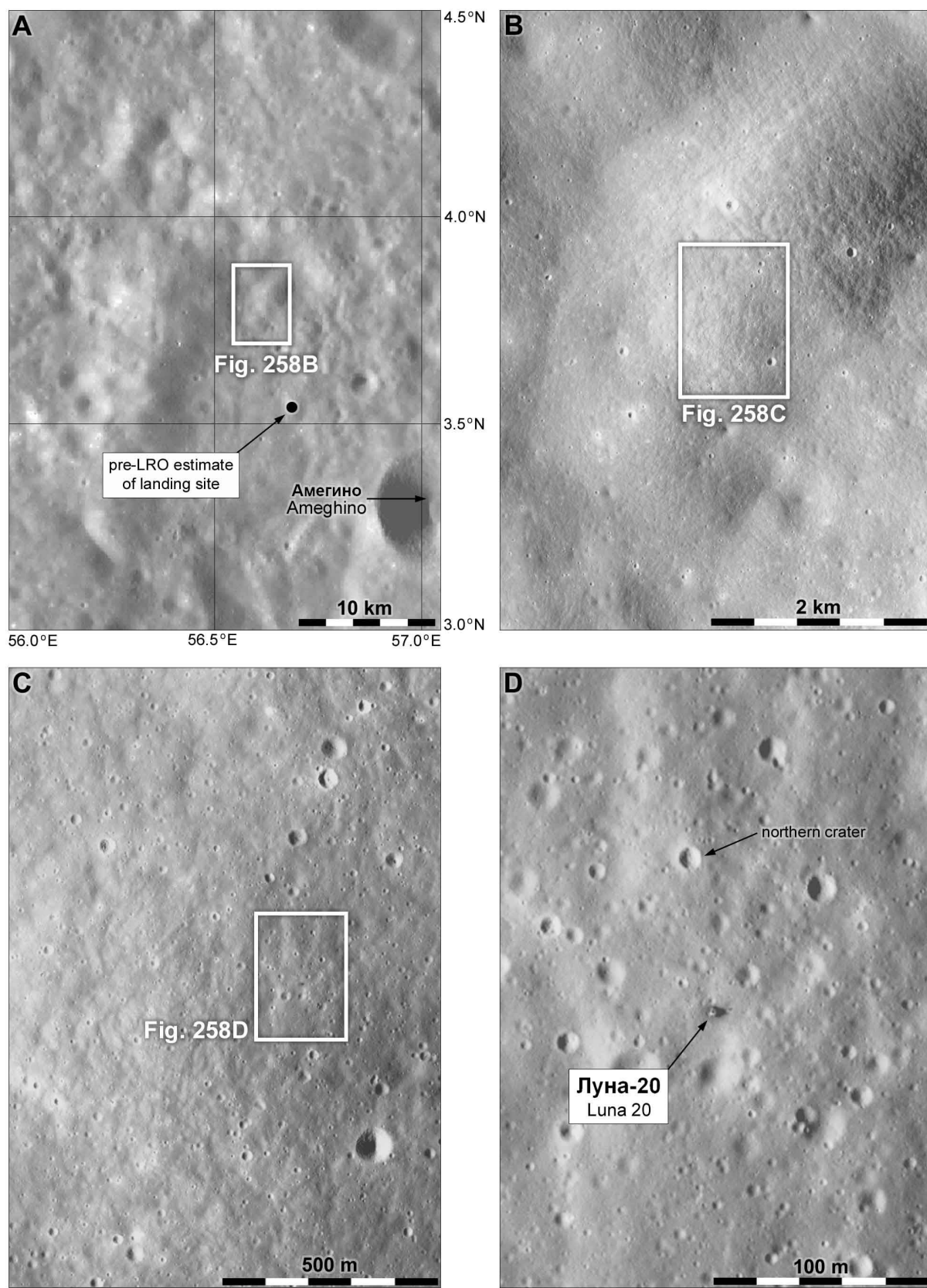


Figure 258. The Luna 20 landing site. B, C and D are parts of LROC NAC image M119482862R.

The drill was lowered and it collected 50 grams of regolith samples. This was less than intended because the drill struck a hard object, presumably a buried rock, at a depth of about 15 cm, causing the drill to overheat. Drilling was abandoned and the small sample was raised and placed in the return capsule. The return stage was launched from the Moon after a stay time of 27.65 hours on 22 February, carrying its samples in a sealed capsule. This separated from its ascent stage when still 52000 km from Earth and landed in the Soviet Union late on 25 February during a blizzard. The samples were recovered from an island in the Karkingir River, 40 km northwest of Dzhezkagan, the following morning (Barsukov and Surkov, 1979). The Luna 20 samples dated the Crisium basin at about 3.85 billion years, almost the same as the age of the Imbrium basin (Wilhelms 1987).

Figure 257A shows the region around the Luna 20 landing site. The landing took place in a broad valley west of the 10 km diameter crater Apollonius C. Figure 257B is an enlargement of 238A showing the landing site showing pre-LRO attempts to locate the landing site. Tracking suggested it had landed about 20 km west of Ameghino, using the cartographic control of the time (Heiken and McEwen, 1972). A position 10 km northeast of this was marked on a map by George A. Burba of the V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow, on a map kindly made available to the author. Stooke (2007) attempted to locate the landing by matching horizon features in the panorama with details of the terrain on the northern rim of Ameghino, apparently confirming Burba's analysis, but LRO images show that this identification was incorrect. The LRO location is identified in Figure 258, and the horizon image location ('far field ridge') is shown correctly in Figure 260.

Figures 259A shows the two ends of the Luna 20 panorama, rotated to show a level horizon. Figure 259B is a composite of all published fragments of the Luna 20 panorama. A gap in this reconstruction may not exist but the images are not clear enough to establish an overlap. Figure 259C is a reprojection of 259B to give a flat horizon. The left end of the panorama faces roughly south, the right end roughly north. Figure 259D shows the image orientation on a magnified LRO image base. A relatively fresh-appearing crater north of the landed spacecraft is identified as 'northern crater' in Figure 258D. Several depressions 1500 m south of the lander are identified in Figure 260A and 260B. A ridge forming the southern horizon is identified in Figure 260B.

Figure 259E is a small section of an image taken before sampling, showing the drill target area. Figure 259F was taken just after sampling, and a wider view is presented in Figure 259G. The drill had been raised, leaving a dark ring to the left of the drill where it touched the surface. Figure 259H was taken after the sample had been placed in the sample container with the drill resting on the ground. White circles indicate the drill hole. Comparison of the hole in 259G and 259H shows that the images were taken by different cameras, 259G from the right-mounted camera, 259H from the left-mounted camera. Each camera could view a scene extending from its horizon to the sampling area, giving stereoscopic viewing of the area to be drilled. Images were provided courtesy of MIIGAiK, and other details were provided by Don P. Mitchell and Ted Stryk and from the Lavochkin website.

Figure 260A is the view to the south, reprojected to help locate surface features. Matching features are shown by labels in this and the LRO image (Figure 260B). These features were misrepresented in Stooke (2007) but are now confirmed by better knowledge of the image orientation and the use of synthetic oblique views in LRO Quickmap.

Barsukov, V. L. and Surkov, Io. A. (eds), 1979. Грунт из материкового района Луны (Soil from the highland region of the Moon). Moscow: Nauka.

Heiken, G. and McEwen, M. C., 1972. The geologic setting of the Luna 20 site. *Earth and Planetary Science Letters*, v. 17, pp. 3-6.

Stooke, P. J., 2007. *The International Atlas of Lunar Exploration*. Cambridge: Cambridge University Press.

Wilhelms, D. E., 1987. *Geologic history of the Moon*. USGS Professional Paper 1348. Washington, D. C.: U. S. Government Printing Office.



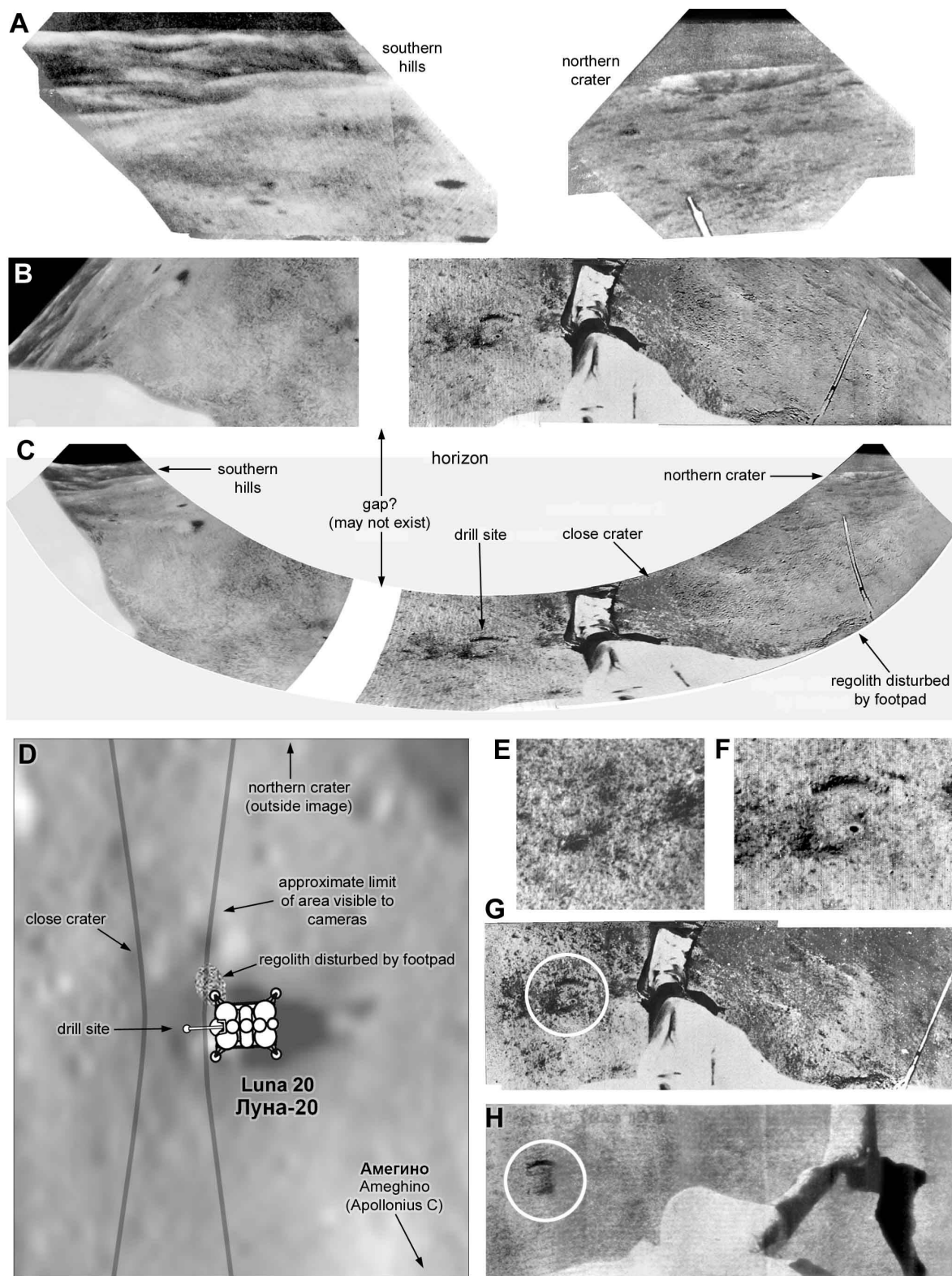


Figure 259. Luna 20 images. A: horizon views. B: composite panorama. C: reprojected panorama. D: orientation of panorama established by identified landmarks. E, F: drill site before and after drilling. G, H: images of the drill hole (circled) from the two cameras. Image fragments are from MIIGAiK, Don Mitchell, Ted Stryk and the Lavochkin website.

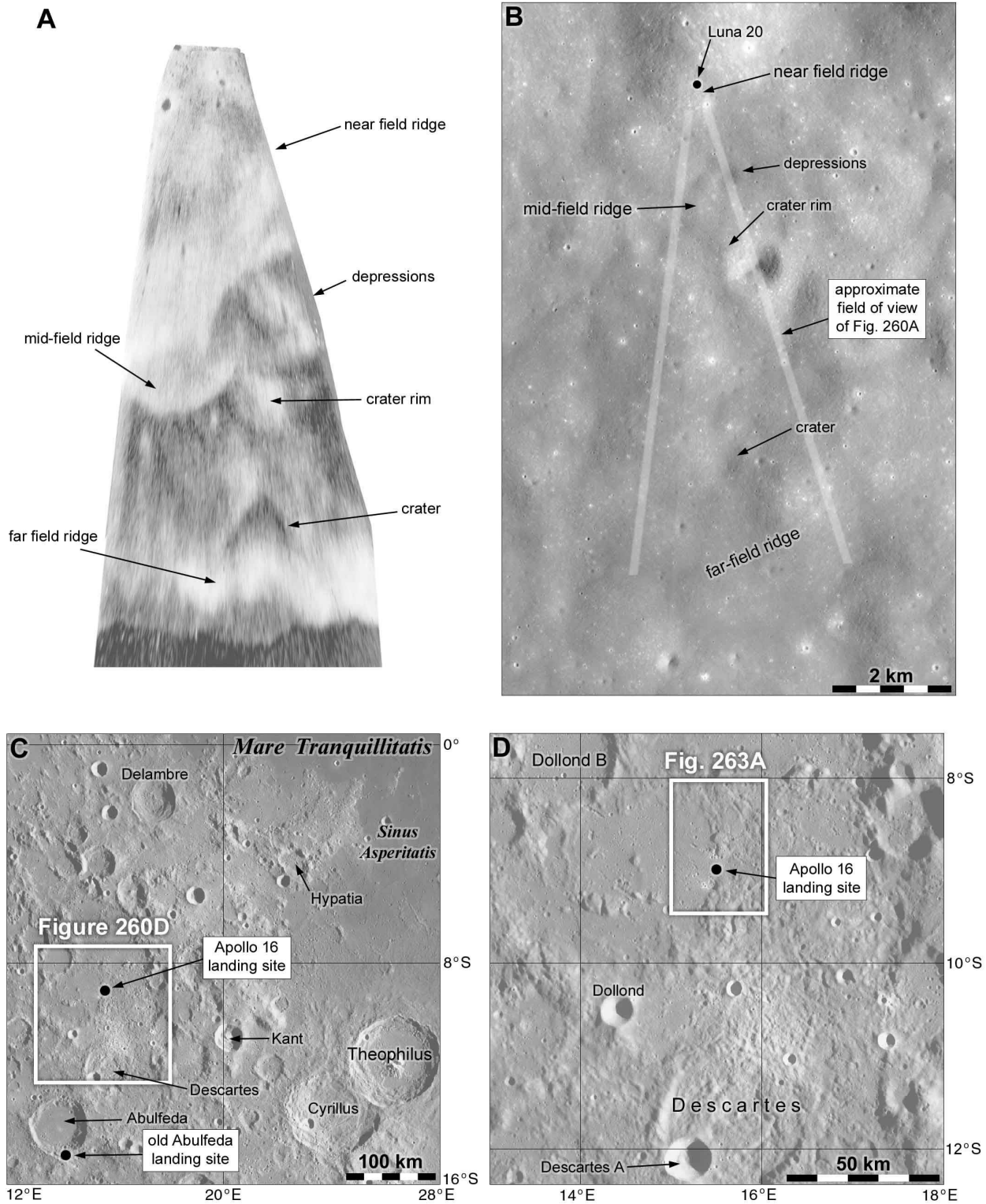


Figure 260. Luna 20 and Apollo 16. A: reprojected Luna 20 panorama section showing the southern horizon. B: LRO wide angle mosaic showing the field of view of the surface image and identified features. C: The Apollo 16 landing region.

16 April 1972: Apollo 16

The Apollo 16 crew consisted of Navy Captain John W. Young, Commander, who had previously flown on Gemini 3, Gemini 10 and Apollo 10, and would later fly on STS-1 and STS-9; Navy Lt-Commander Thomas K. Mattingly II, Command Module Pilot, who later flew on STS-4 and STS-51C; and Air Force Lt-Colonel Charles M. Duke, Jr., Lunar Module Pilot. The Apollo 16 backup crew consisted of Fred W. Haise Jr. (Apollo 13), Stuart A. Roosa (Apollo 14), and Edgar D. Mitchell (Apollo 14).

Apollo 16 was launched at 17:54 UT on a Saturn V from Pad 39A at Kennedy Space Center. The launch had been postponed from 17 March to allow minor repairs. The vehicle entered a parking orbit at 18:06 UT and its translunar injection burn occurred at 20:28 UT. The CSM separated from the S-IVB upper stage at 20:59 UT and docked with the LM at 21:16 UT. The S-IVB continued to a lunar impact, but helium venting prevented a planned course adjustment. The SIVB radio transmitter failed on 17 April at 21:03 UT so tracking was lost. It struck the lunar surface on 19 April at 21:02 UT, at 1.921° N, 24.623° W (Figures 261, 262) with a velocity of 2.5 km/s, 11° from a vertical trajectory, providing a signal for the Apollo 12, 14 and 15 seismometers, as discussed below.

Apollo 16 made a trajectory correction on 18 April at 00:33 UT. During translunar coast a CSM navigation problem was discovered in which a false indication would cause loss of inertial reference, this was solved by a real-time change in the computer program. The SIM bay door covering the orbital remote sensing instruments was ejected on 19 April at 15:57 UT and the spacecraft entered lunar orbit at 20:22 UT. After two orbits its low point was dropped to 20 km.

On 20 April at 15:24 UT, Young and Duke entered the LM 'Orion'. They separated from the CSM 'Casper' at 18:08 UT. The descent to the surface was delayed for six hours by a potentially serious propulsion system anomaly, which was eventually resolved. The LM landed on 21 April at 02:24 UT in the Descartes region (Figure 260 C, D) at 8.97° S, 15.50° E (LRO coordinates 8.973° S, 15.501° E). Young and Duke made three EVAs lasting a total of 20.25 hours, using a Lunar Roving Vehicle (LRV) to cover 27 km. They brought back 94.7 kg of lunar samples, took many photographs, and set up an ALSEP and other experiments.

Orion took off on 24 April at 01:26 UT after 71.0 hours on the surface and docked with the CSM at 03:35 UT. After equipment and the 95.7 kg of lunar samples were transferred to the CSM, the LM was jettisoned at 20:54 UT. It was supposed to be crashed near the landing site (Figure 264A) to provide a seismic signal, but it lost attitude control and was abandoned in orbit. It did eventually crash as discussed below.

Several other minor technical problems also affected the mission. The instrument boom which supported the orbital mass spectrometer could not be retracted, so it was ejected and must also have struck the lunar surface within 10° of the equator at an unknown date. Concerns about the Service Module propulsion system led to a one day reduction in orbit time, and the cancellation of an orbit adjustment designed to place the Apollo 16 subsatellite (Particles and Fields Satellite 2, PFS-2) in its desired orbit. As a result the subsatellite was ejected at 21:56 UT into an elliptical orbit with a lifetime of about one month rather than the full year intended. The subsatellite struck the lunar surface on 29 May (Figures 261C, D).

The trans-Earth injection burn began on 25 April at 02:16 UT. At 20:43 UT that day Mattingly began a 1.4 hour deep space EVA to retrieve film from the SIM bay cameras. The CM separated from the SM on 27 April at 19:17 UT and splashed down on 27 April at 19:45 UT at 0° 43' S, 156° 13' W, in the Pacific Ocean 350 km southeast of Christmas Island and 5 km (3 mi) from the recovery ship USS Ticonderoga. Total mission time was 265.85 hours. The Apollo 16 Command Module is now on display in the U. S. Space and Rocket Center in Huntsville, Alabama.

The Saturn IVB upper stage impact location is shown in Figure 261A. The target point was 2° 18' S, 31° 42' W (NASA 1972a), though lack of accurate control made this uncertain by 10° (300 km) or more. The actual impact was estimated just after the flight to have occurred at 1.83° N, 23.30° W, from tracking prior to loss of communications (NASA 1972b). This was later refined to 2.24° N, 24.49° W. Timing of the resulting seismic signals suggested a location of 1.3° N, 23.8° W, uncertain by about 0.5°, according to the National Space Science Data Center. The impact crater was eventually located in LRO images at 1.921° N, 24.623° W (Robinson, 2015), 200 km from the target.

Figure 261C shows the subsatellite impact area. The Apollo 16 subsatellite PFS-2 carried a plasma analyzer and a magnetometer to study the lunar magnetic and plasma environment, and provided information on the lunar gravitational field via its radio transponder. The spin-stabilized 36 kg subsatellite was placed in a 119 minute orbit inclined 11° to the equator. Eventually on 29 May 1972 the signal ceased, after 34 days and 425 orbits, and it is assumed to have crashed at that time. There was no close tracking of the impact, which occurred on the far side, but Meador (2022a, b) states that NASA's prediction at the time was for an impact at 20:31 UT on 29 May 1972, at 10.16° N, 111.94° E. His own analyses using two different sources for initial orbit conditions gave impact predictions of 11:02 UT on 30 May 1972 at 8.88° N, 98.94° E, or 17:16 UT on 29 May 1972 at 10.16° N, 107.89° E. The second is a closer match to the original prediction. The impact is assumed to have occurred in the area of the original NASA prediction, probably on the east-facing slope of Lobachevskiy's western wall at about 10.16° N, 111.66° E, about 300 km from the Lunar Orbiter 2 impact site, although other east-facing slopes further west might also be candidates. The area is shown enlarged in Figure 261D.

The regional setting of the Apollo 16 landing site is shown in Figure 260C. The landing site is about 300 km south of Mare Tranquillitatis in the cratered southern highlands, and about 200 km north of the old Abulfeda site (Figures 113C, 260C) which it replaced as the preferred site for studying potential highland volcanism. The site was referred to as Descartes though it actually lies about 70 km north of Descartes itself, a crater which is almost hidden under a blanket of material that forms small hills throughout this area (Figure 260D). An unnamed 140 km wide crater, also nearly buried, spans the full width of Figure 260D with the landing site at its center. Figure 263 locates the landing site.

Figure 264A shows the landing site in more detail. Figure 264B shows a closer view of the hills, referred to during planning as 'north hills' and 'south hills', and the plains which lie between them and extend far to the west across the buried crater. Some informal feature names used during the mission are indicated. Informal placenames around the landing site, used in crew training and mission operations, are compiled in Figure 264B from pre-mission planning documents used by the Science Working Panel, from their minutes, and MSC (1972). The base image is part of Apollo 16 panoramic camera frame 4558. The landing site is dominated by two mountains (Stone Mountain and Smoky Mountains, sometimes called Smoky Mountain) and two fresh ray craters (North Ray and South Ray). Cayley Plains (strictly speaking the Cayley Formation) is a geological unit name applied to all patches of relatively smooth and level material filling depressions in the region, but it was often used at this location as if it were a local placename.

Cinco is a cluster of five craters on Stone Mountain. Canoe is an elongated depression, a northwesterly extension of Big Sag, slightly north of the edge of this map. It lies mostly outside Figure 264B but is also visible in Figure 264A. The name Dot (referring to Charles Duke's wife Dorothy) was originally assigned to a crater northwest of Palmetto (Dot 1 on the map). It would have been the site of Station 13 in Figure 254C. When the EVA was redesigned the name was moved to a feature just north of Palmetto (Dot 2) so it would still be on the itinerary. The name Haystack also was used in two locations, most often for a small fresh crater near the western edge of the map (Haystack 1 on the map), but also for a hill north of North Ray (Haystack 2).

According to the Apollo Lunar Surface Journal (ALSJ), Spook was a nickname for Capcom Tony England's wife and Buster was his dog. Cat stood for Charles and Tom (Duke's sons), Palmetto represented Duke's home state (South Carolina) and Gator represented Young's home state (Florida, though he was born in California). Lone Star was named for Texas. England said that WC (the euphemistic name for a toilet, 'water closet') was applied to a crater which was likely to be 'flushed' or dropped from an EVA if it was the last science station on that traverse. Young said 'I named Plum Crater for my daughter Sandy [Sandra] whom I called Sugarplum.'.... "Buster was named for my son, John, who as a youngster I called Buster Brown." (p. 180 in Young, 2012).

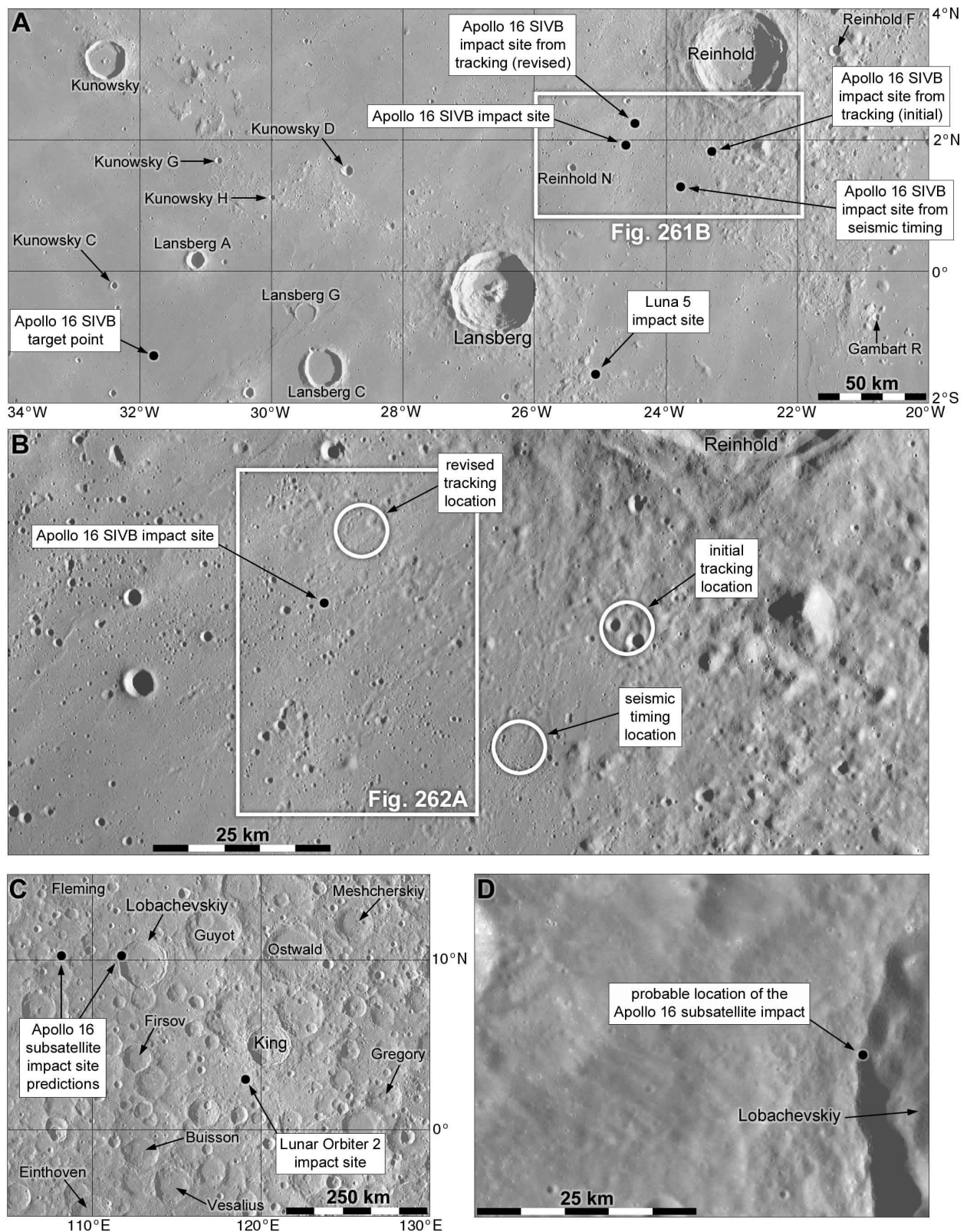


Figure 261: Apollo 16 SIVB and subsatellite impact sites. A: SIVB target and impact sites. B: SIVB impact site and estimated locations. C: subsatellite impact region. D: probable subsatellite impact area on the western rim of Lobachevskiy crater.

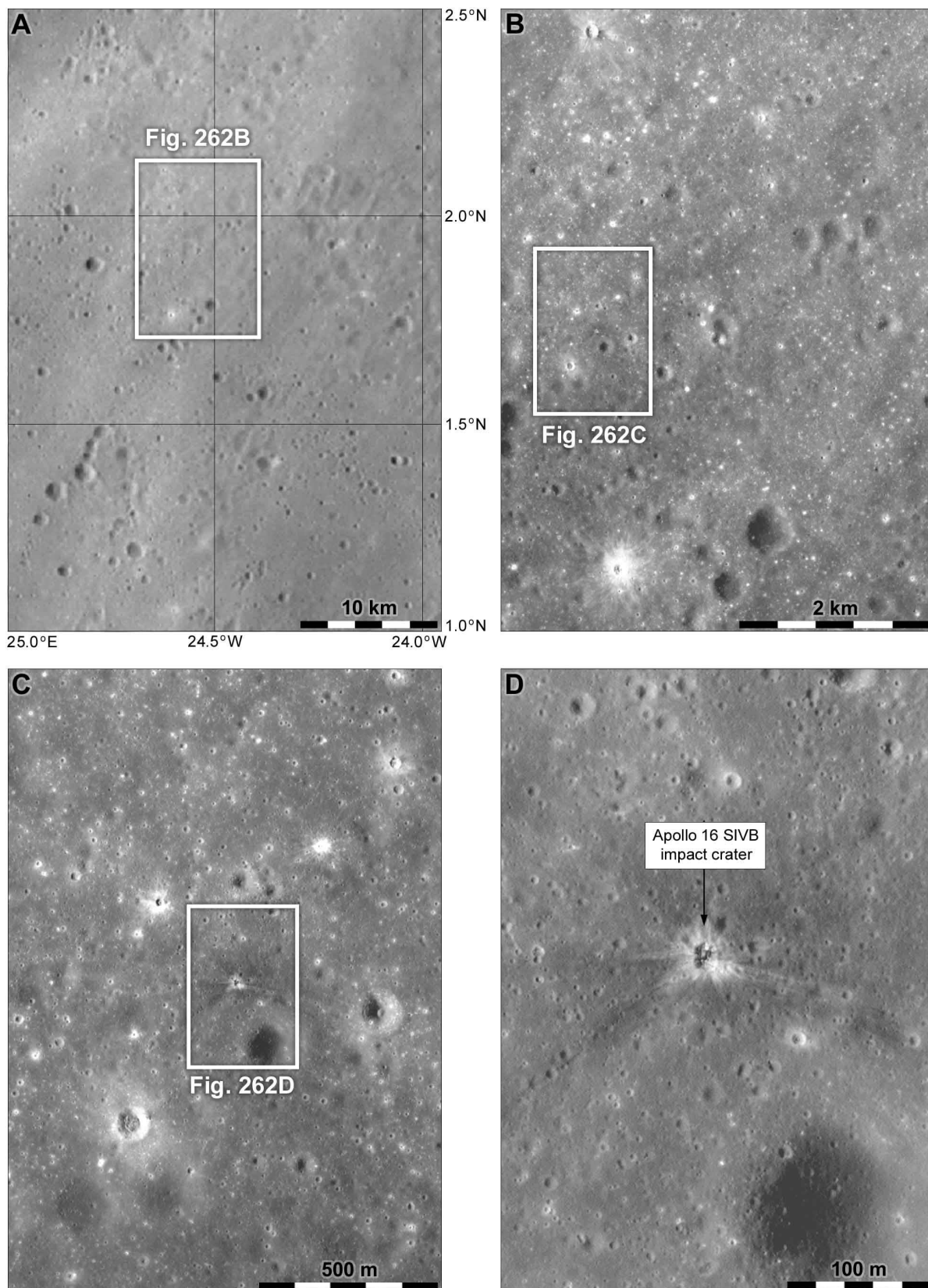


Figure 262. Apollo 16 SIVB impact site. B-D: LROC NAC image M183689432L.

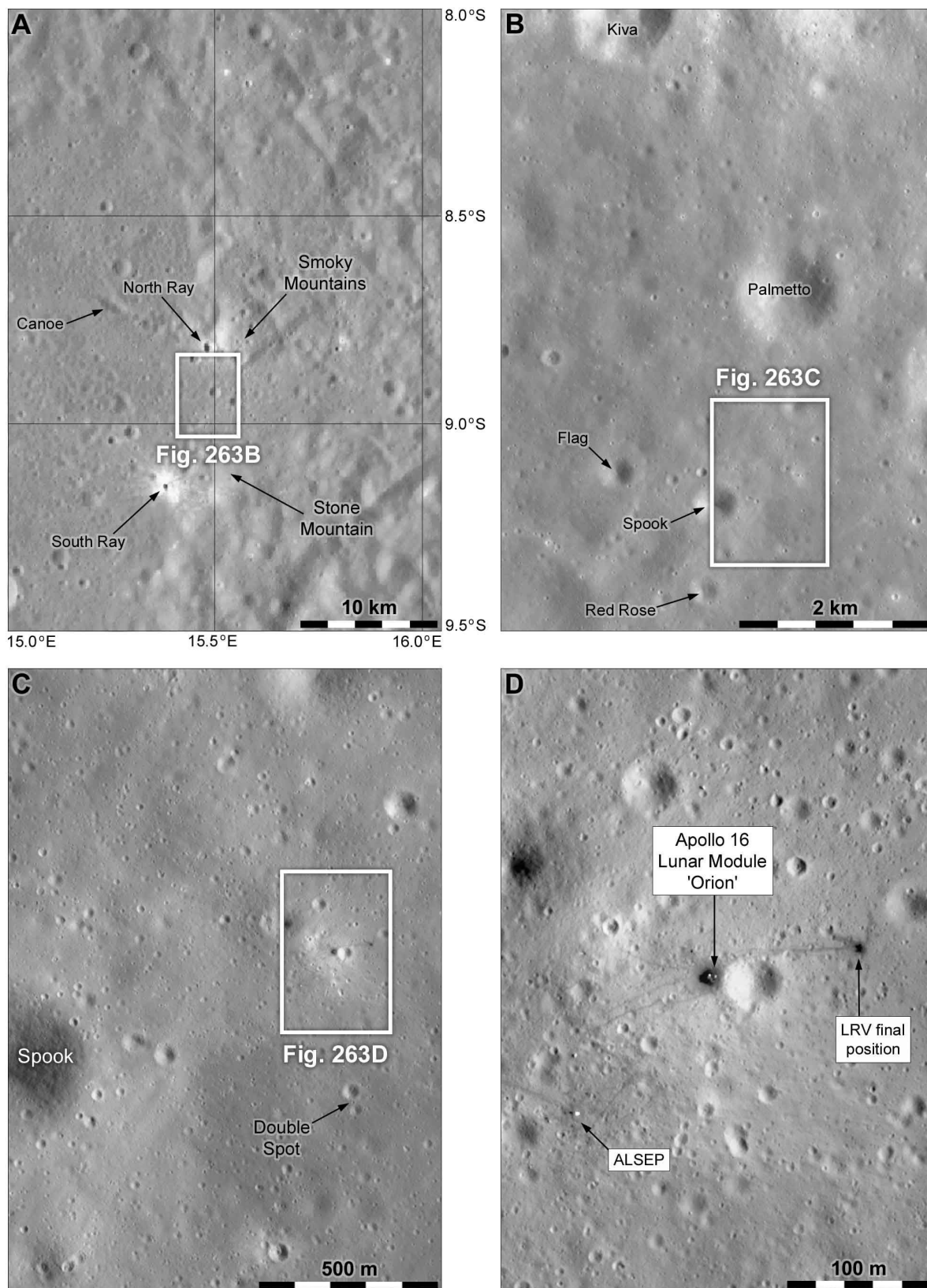


Figure 263. Apollo 16 landing site. C and D are from LROC image M144524996L.

Three possible landing points for Apollo 16 are indicated in Figure 264B (MSC, 1972). The smoothest, point 2, was selected for the mission. Figure 265 is an index to the following EVA maps. The LM area and ALSEP are shown in Figures 266 and 267. Figure 266A shows activities around the landing site and ALSEP area. 'S' indicates a sampling location. Young flew the LM over a 30 m crater and landed just west of it. During EVA 1 the Solar Wind Collector (SWC), a far UV telescope and the flag were set up near the LM. The ALSEP was carried 80 m southwest of the LM and deployed. EVA 1 is mapped in Figures 268 and 269, EVA 2 in Figures 270-274 and EVA 3 in Figures 275-279. The LM landed about 300 m north of the target point. The planned and actual landing sites and routes are shown in the EVA summary maps (Figures 268, 270, 275).

Details of the mission plans and initial results were presented by MSC (1972a) and NASA (1972a, b) before launch and by MSC (1972b) and NASA (1972c) after the mission. Ulrich *et al.* (1981) summarize the results at Descartes and show the best estimate at the time of the rover routes. A brief summary of surface activities follows. The early EVA activities would have been broadcast by a television camera set up on a tripod west of the LM as on Apollo 15, but an antenna problem prevented its use. The broadcast began only when the LRV with its own antenna was set up.

After leaving the LM the crew offloaded the LRV and ALSEP, and set up a small far ultraviolet telescope and the flag. The telescope was placed in the LM shadow and made observations of Earth, the Large Magellanic Cloud, the Galactic Centre and eight other astronomical targets on film during the 3 day stay. Duke carried the ALSEP to a point about 100 m SW of the LM where it was unpacked and set up. An unfortunate accident at this point ruined one of the experiments: Young's foot caught a cable from the Heat Flow Experiment and pulled it loose. Although a possible repair method was devised on the ground, time later in the mission was too limited to attempt it. A deep core sample was drilled nearby, and a 'thumper' was used to generate seismic signals for a row of geophones to probe subsurface structure, as on Apollo 14.

The crew then drove out to Station 1 at Plum crater on the rim of Flag. Duke referred to a depression south of the rover route as 'Hidden Valley', perhaps a mistaken reference to 'Eden Valley' (Figure 268A). The Cayley Plains material was sampled at Flag (named for Flagstaff), and a trench was dug and sampled in the rim of Plum crater. At Station 2, between Spook and Buster craters, the Lunar Portable Magnetometer was deployed to measure the local magnetic field, and samples were collected. In general the magnetic field was stronger at Descartes than at the other Apollo sites, though still very weak by terrestrial standards. The crew then returned to the ALSEP, a little behind their tightly scheduled timeline. Sampling was deleted at what would have been called Station 3. The Active Seismic Experiment mortar was armed and the core tubes were retrieved. Back at the LM, Duke deployed the Solar Wind Collector, the Far-UV telescope was reset, and samples were loaded into the LM. EVA 1 lasted 7.2 hours and covered 4.2 km.

The plan for the second EVA (from MSC, 1972a) is shown in Figure 270 as a gray line. The actual EVA, drawn in black, is modified from DMA (1975). EVA 2 began with a long drive to Station 4 on Stone Mountain. The most distant station was visited first to allow time to walk back if the rover failed. Station 4 was in the Cinco crater cluster, not quite as far south as originally intended. The largest of these craters, adjacent to Station 4, is labelled Cinco on the DMA map, but the name really referred to all five craters. They were distinguished as 'Cinco a', 'Cinco b' and so on if necessary (Figure 270).

Stations 5 and 6 were at lower elevations on the mountain. Station 7 was omitted and the astronauts drove to Station 8 to sample ejecta from South Ray crater. Station 9 was in a ray-free area of the adjacent plains. Here Young carefully obtained a sample free from all contamination (LM exhaust and leaking EVA suits) by 'sneaking' carefully towards a rock from the north and sampling from its opposite (southern) side. A final stop was made at Station 10 between the ALSEP and the LM. Here a drive tube (hammered rather than drilled) was used to obtain a double soil core sample, and a penetrometer measured soil characteristics. Total EVA 2 time was 7.4 hours, and the distance covered was 11.3 km.

EVA 3 took the crew to North Ray crater, north of the LM. It was shortened to ensure adequate time to prepare for liftoff. There had been some discussion of abandoning it altogether, but the sampling objectives at North Ray Crater were deemed too important to give up. On the way to Station 11 a large boulder was identified as another suitable target, and this became Station 13 on the return journey. All other stops on this EVA were dropped.

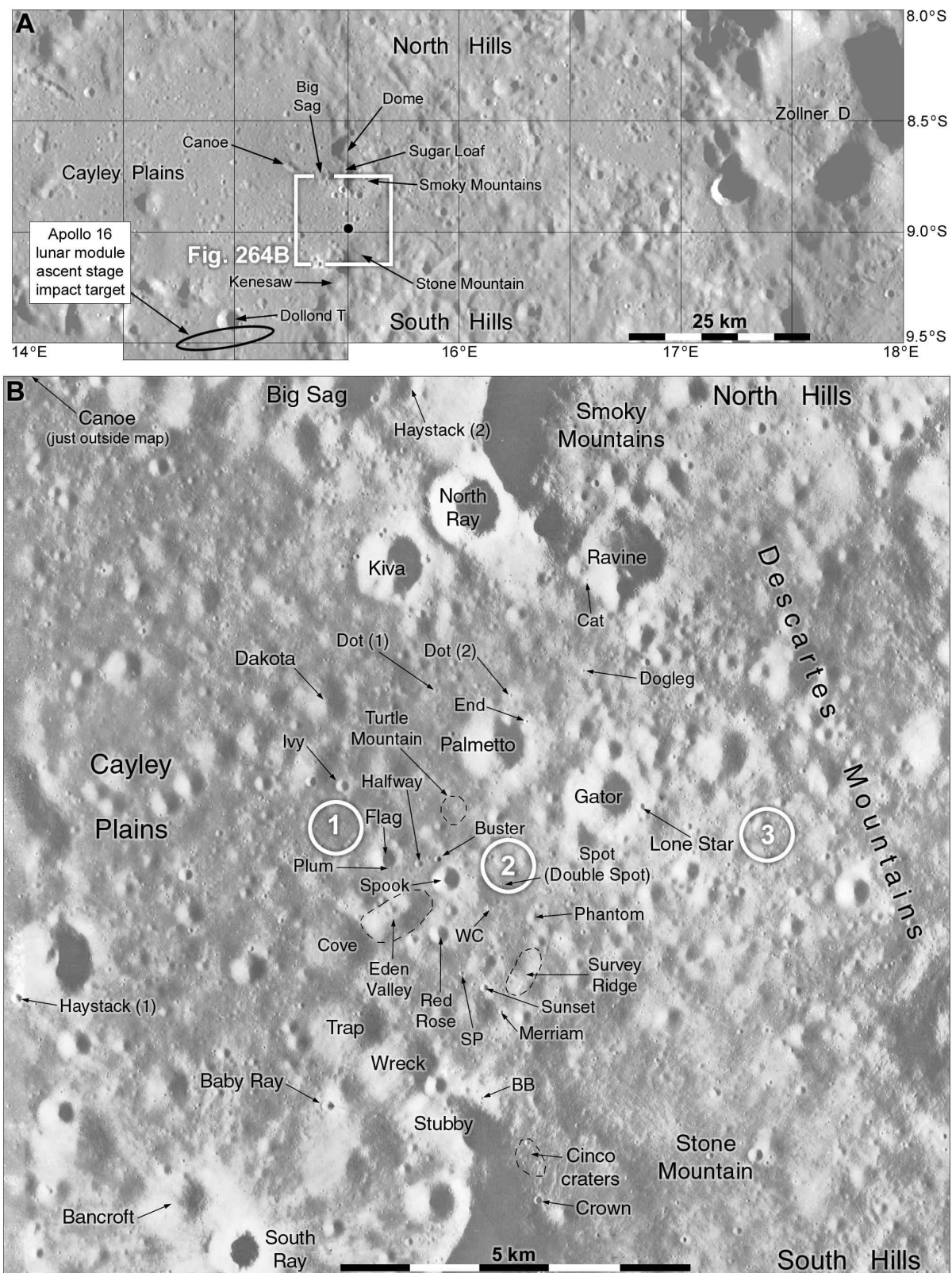


Figure 264. Informal names at the Apollo 16 landing site. A: regional names, with the lunar module ascent stage impact target. B: local names on an Apollo 16 panoramic camera mosaic. Circles 1, 2 and 3 are alternative landing sites (MSC, 1972).

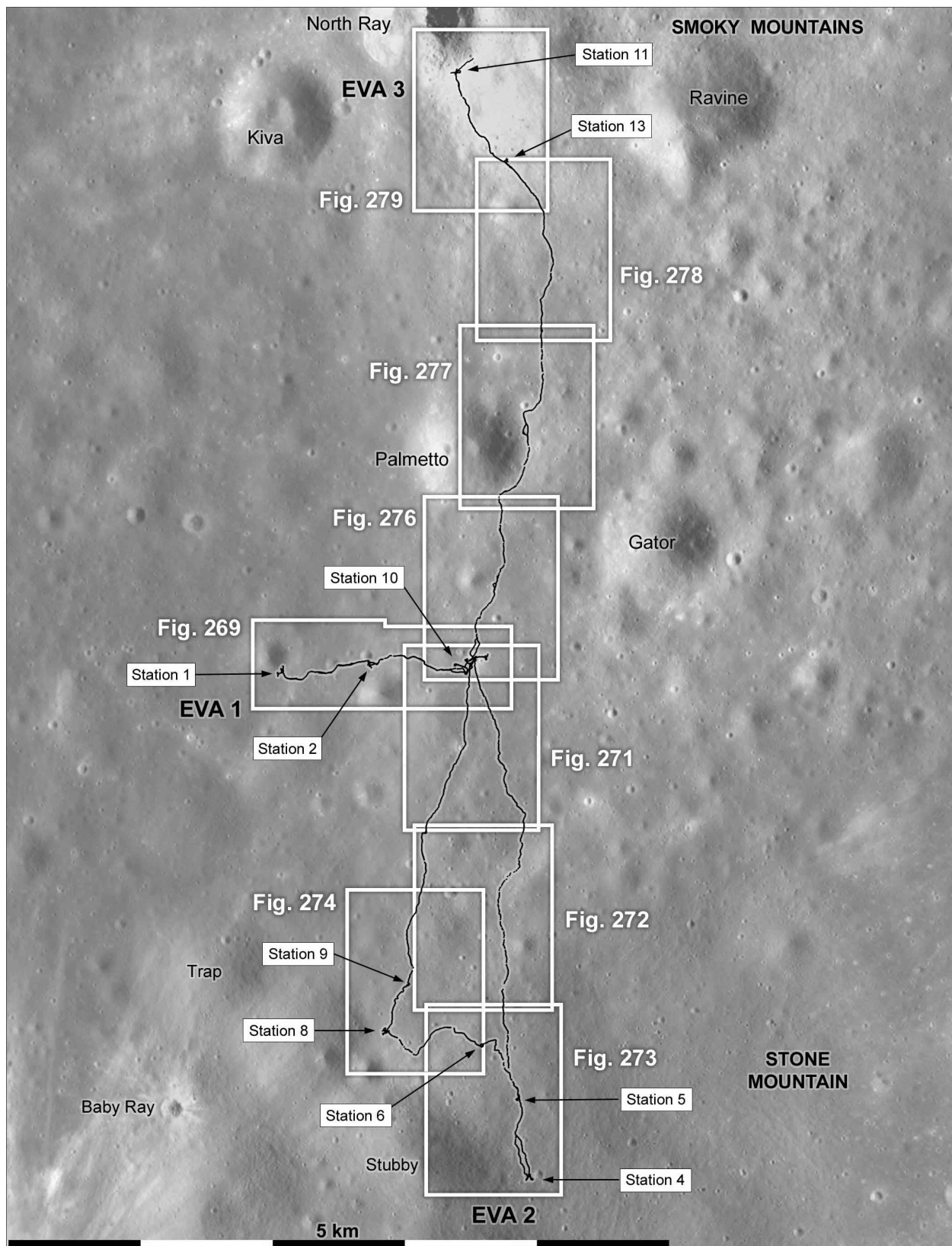


Figure 265. Apollo 16 EVA routes and index to EVA maps.

At Station 11 light and dark boulders were sampled extensively, and the crater was photographed in detail in the hope of observing stratigraphic layering in the walls. Photography included four panoramas (two, both in stereo) taken with a polarizing filter to provide additional physical information on the crater walls. The largest rock in the vicinity, dubbed House Rock for its size, would have been the planned Station 12 location. Station 13, Shadow Rock, was chosen because its overhanging south side might protect soil samples which had been shaded since the emplacement of the boulder, possibly trapping small quantities of gases.

A final stop was made at Station 10' (10 prime) north of the ALSEP (Figure 266A). A double drive tube sample and rake samples were taken here. A rake sample was also collected at this time near the Station 10 location. Finally the LRV was parked east of the LM at the 'VIP' site to provide video of the LM ascent stage liftoff and subsequent impact. A rock was collected and placed on top of the Lunar Portable Magnetometer (LPM) for a reading of its magnetic characteristics before being returned to Earth. The crew then retrieved the Solar Wind Collector and loaded their samples, films and other items into the LM before leaving the lunar surface. Total EVA 3 time was 5.7 hours. The distance traveled was 11.4 km.

A more detailed account of the EVAs follows, based on the transcripts from the Apollo Lunar Surface Journal.

The landing was delayed for 6 hours by a problem with the Command-Service Module which might have required the Lunar Module to serve as a 'lifeboat' as on Apollo 13. Young landed the LM with a jolt and the crew quickly looked around, commenting on Stone Mountain which though not as high as the Apollo 15 mountains was still a significant landmark. Duke said 'Old Orion is finally here, Houston' and Young said he could see the crater pair Double Spot to his left (south). He was mistaking two small fresh craters within 100 m of the LM for the more subdued and distant Double Spot, which was hidden behind a local rise (Figures 268, 269). He noted that the site was a rolling landscape with numerous ridges, not as flat as they had expected, and both astronauts commented on the many rocks they could see. Even from the LM window Young could see signs that the rocks might be breccias rather than the volcanic rocks they were expecting. Crown crater on Stone Mountain was visible from the LM and the mountain slopes appeared to be driveable. After this short survey of the site the crew were given permission to stay on the Moon.

Houston, in the person of Apollo 15 astronaut Jim Irwin acting as Capcom, provided a list of updates and changes to procedures. Young checked a balky antenna to see if it would steer properly after the jolt of landing, but it was still stuck. They removed their bulky flight suits and photographed the views out of the LM windows. This was the only window panorama of the mission as they did not take post-EVA window images to document activities, as all other Apollo crews had done. Young mentioned craters Cinco and Echo when describing Stone Mountain. Cinco is a set of five small craters at what would become Station 4 and he would have been referring to the largest, which was clearly visible. The name Echo is not recorded on any Apollo 16 maps but might refer to the crater above Crown in Figure 268B. Duke pointed out that a level location for the ALSEP deployment might be difficult to find.

Duke then began a detailed description of the surroundings for the benefit of geologists in Houston. He noted several black and white rocks, and a nearby ridge which blocked the view northwards to North Ray and Smoky Mountains. Young described South Ray ejecta and rays, and Duke pointed out that the LM exhaust threw up less dust than had been seen at earlier sites. Then the astronauts slept in preparation for the first EVA.

After waking the astronauts had breakfast and discussed EVA 1 with Capcom Tony England. After setting up the ALSEP they would drive west to Flag crater and look for samples of the local Cayley Formation plains material, taking care to avoid South Ray ejecta if possible. They would save time and LM power by omitting the TV coverage of LM egress and LRV deployment. They tried moving the stuck antenna again without success, and then dressed for the EVA. Duke's helmet was wet with orange juice after an accident with a drink bag inside his suit while they waited for the CSM problem to be resolved. It had to be dried before he could use it.

They depressurized the cabin and opened the hatch, and Young crawled out backwards onto the 'porch'. He threw down a jettison bag full of items they no longer needed and lowered an equipment transfer bag full of cameras and other items to the ground on a lanyard. Another lanyard released the MESA cover. As Young reached the surface he said 'Mysterious and unknown Descartes ... Apollo 16 is gonna change your image' and he referred to himself as 'Brer Rabbit ... back in the briar patch where he belongs'. This was a reference to a popular southern US story by Joel Chandler Harris. He kicked the jettison bag under the LM, picked up a rock to test mobility in his suit and

noted the 25 m diameter crater immediately behind the LM. They had flown over it just before landing. The actual landing had occurred inside a very subdued old crater about 250 m across whose rim blocked their view of some middle-distance features including Double Spot.

Duke clambered out of the LM and pulled the hatch nearly closed. When he reached the ground the astronauts adjusted the height of the MESA, raising it to make future work easier. This gave them some trouble and took longer than expected. They removed a blanket covering the MESA and the TV camera tripod, which was not going to be used but was blocking access to the drill. Eventually Duke pulled out the drill and tested it to be sure it would work. Young walked around to the LRV and began to deploy it, joined soon by Duke so they could work together on the complex process. Duke noted that the engine bell had not struck the ground, as had happened on Apollo 15, and he pointed out a rock which he thought resembled a vesicular basalt, a rock containing holes which had been gas bubbles in liquid lava. The crew had been sent to Descartes to find volcanic rocks so this might have been expected, but it was probably an impact melt rock rather than basalt.

The LRV unfolded properly and the astronauts checked that the wheels locked in place as intended. They picked the rover up and turned it rather than driving it in the tight space between the LM and nearby slopes. Young's foot became tangled in a rover deployment cable, presaging future problems at the ALSEP. Duke threw two items of packaging they no longer needed and commented on how far they travelled. When the LRV was deployed and prepared for use, Duke took images for a panorama from the northern edge of the crater behind the LM, northeast of the LM (Figure 266). He was asked to photograph the LM itself to document the state of plume defectors under the LM thrusters, after they had observed damaged paintwork, and some exterior panels on the back of the LM which had buckled. Later, CSM pilot Ken Mattingly would photograph the LM Ascent Stage as it returned from the surface to further document the state of the LM. It was as light as possible and so flimsy in places, but still perfectly capable of safe flight.

As Duke took pictures Young drove the rover clockwise around the LM to the area on its north side where they would load it. The ALSJ says the drive was counter-clockwise, but Duke's images show the opposite. A clockwise path would avoid the large crater behind the LM, and LRO images show no tracks east of the crater. The rear steering was not working now but would function properly later. Young moved to the northeastern quadrant of the LM to remove the UV telescope from its equipment bay, and noted a rock with large clasts which was certainly a breccia. Duke looked south to Stone Mountain and observed a ridged surface on it, many small horizontal terraces roughly following contour lines around the slope. These were probably caused by downslope movement of regolith due to impact-induced shaking, an effect seen on many lunar slopes.

Young carried the UV telescope to its deployment position in the LM shadow (Figure 266B) and set it up, enthused about the ease of working in the low lunar gravity, as Duke loaded the LRV with communications and other equipment. The telescope battery was placed outside the shadow, attached with a cable which Young had to take care not to catch his feet on. Then he pointed the telescope to coordinates read up to him from Houston, and left it to work with Duke on the LRV. Duke set up the TV on the rover and aligned the high gain antenna, and for the first time in this EVA Houston could watch the crew work. Next he set up the 16 mm Data Acquisition Camera (DAC), the camera which rarely worked on Apollo 15 but operated properly now. It would record the LRV traverses during each EVA, and Duke also took photographs at frequent intervals as a backup.

Young took the flag from the MESA and unfurled it while Duke opened the doors to the LM equipment bay housing the ALSEP, on the northeast side of the LM. The ALSEP packages were mounted on rails for this mission to help them slide out more easily. Duke threw away two bars he no longer needed, enjoying the distance he could throw in lunar gravity as other crews had done before. Then he collected a camera to photograph the flag which Young had just erected northwest of the LM. Young jumped off the ground as he saluted, twice, as Duke took his pictures, and then Young photographed Duke standing for his salute. As they concluded the flag activities Capcom England told the crew that the US House of Representatives had just passed a new Space bill which included funding for the post-Apollo Space Shuttle project. Young said 'The country needs that Shuttle mighty bad', as without it there was nothing to follow Apollo and Skylab, and he went on to pilot two Shuttle flights including the first launch in 1981.

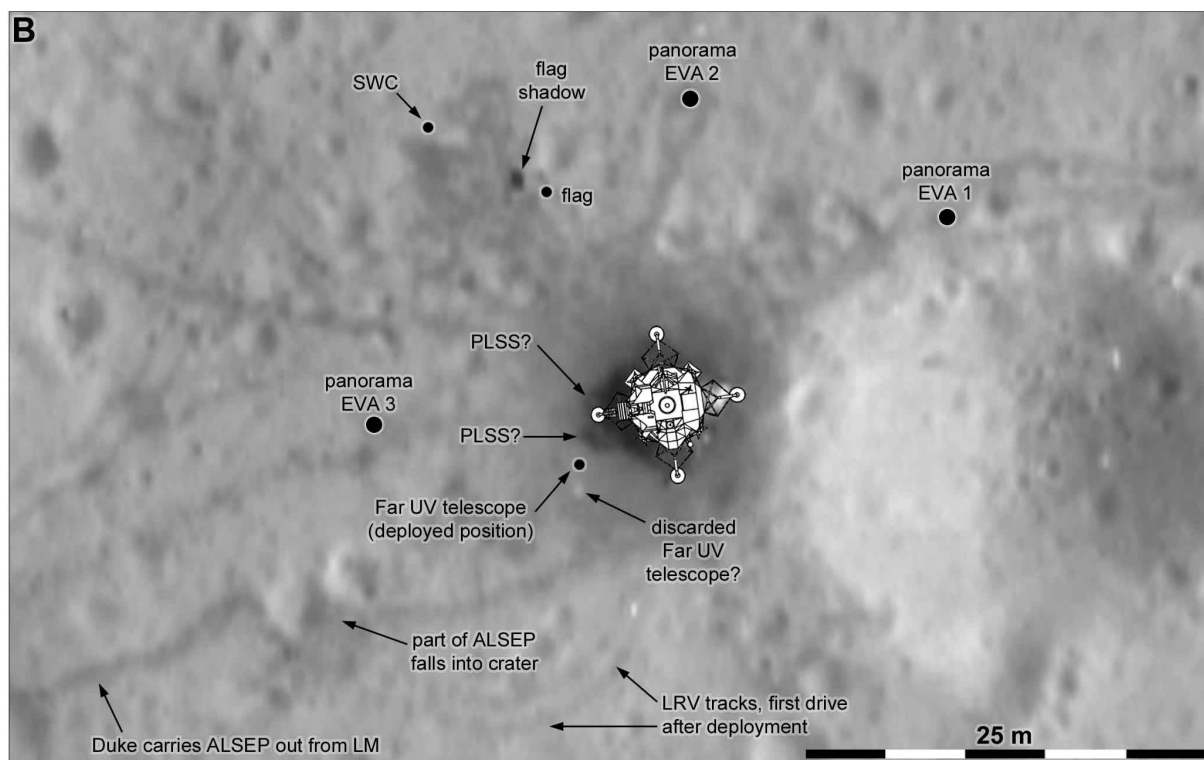
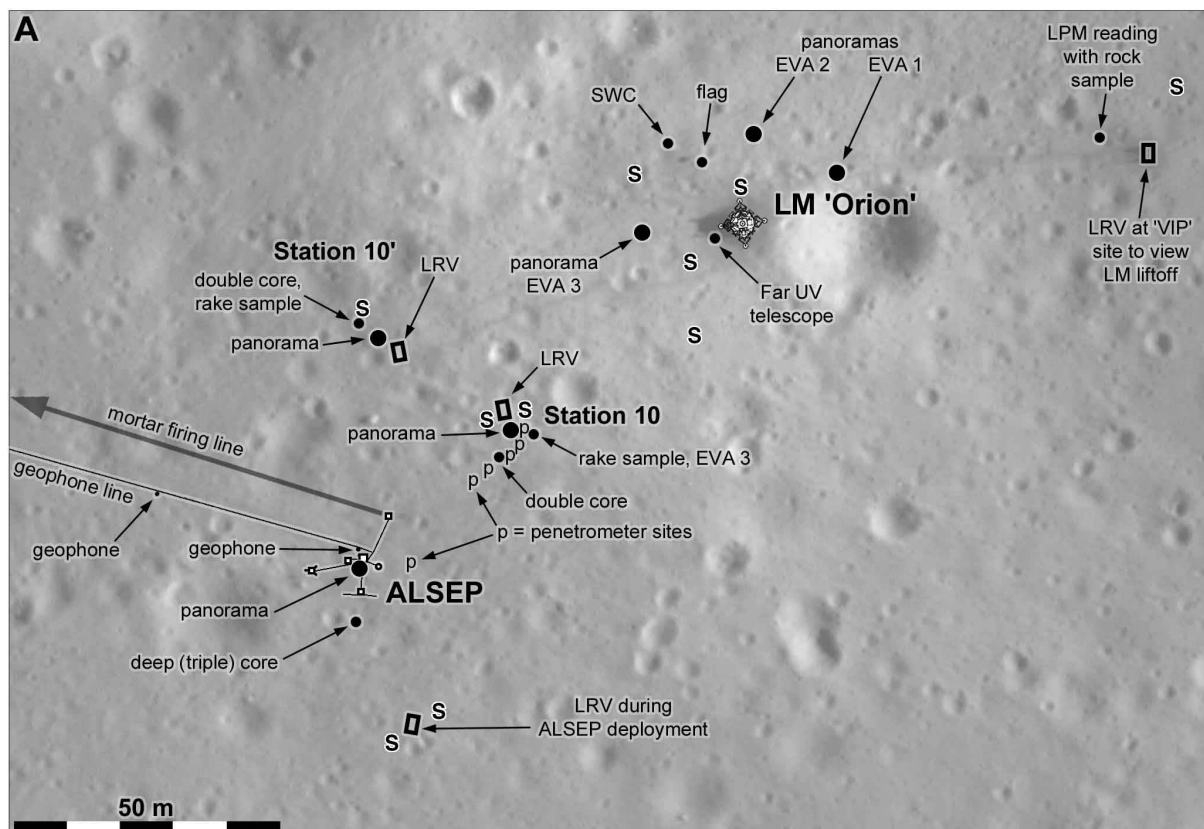


Figure 266. Apollo 16 landing and ALSEP area. A: Lunar Module and ALSEP areas, showing Stations 10 and 10'. B: LM area enlarged. LROC NAC image M129187331L.

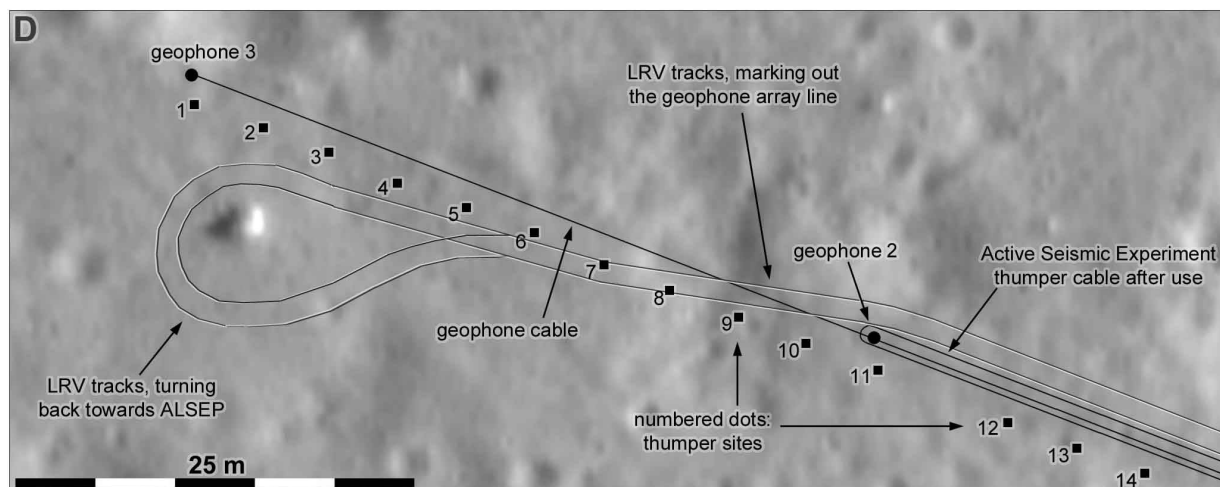
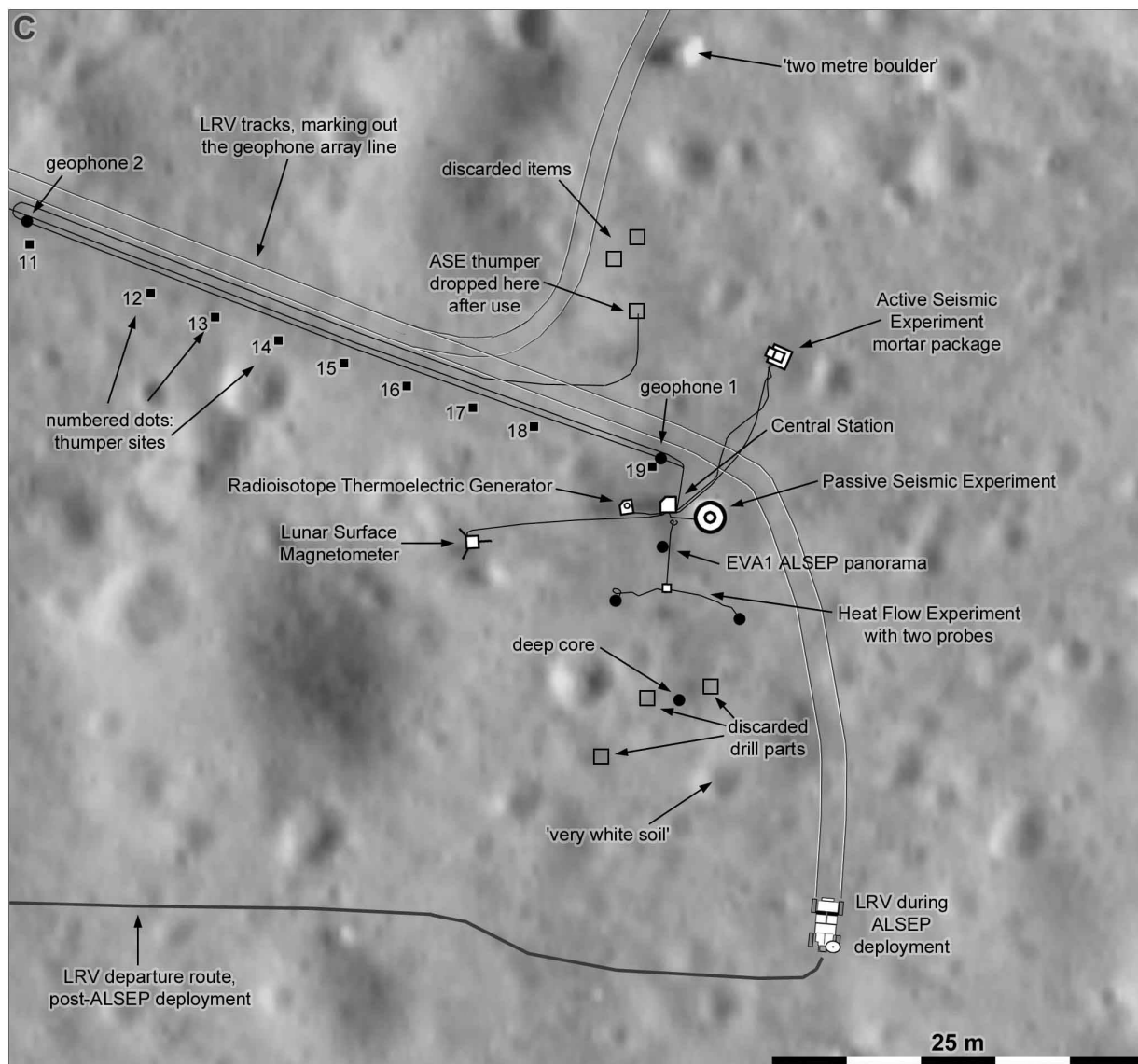


Figure 267. Apollo 16 ALSEP area.

Duke prepared the ALSEP packages and fuelled the RTG with the plutonium fuel rod, and Young returned to the UV telescope to point it at a new target, this time Earth. As he worked on the telescope Duke carried the two ALSEP packages, joined by a carry bar, clockwise around the back of the LM and then southeast towards the site they had chosen for the ALSEP deployment. This was south of the area they had planned but the surface was smoother. One package fell off the bar and rolled into a small crater (Figure 266B), and Duke had to retrieve it and fix it to the bar again. He had adopted a bouncing gait which may have contributed to the accident. He set off, walking more steadily now. He stopped to rest again, then walked out past a 2 m diameter boulder and looked for a place to deploy the equipment. Later he described the big rock as a breccia with white clasts in a darker matrix.

Young prepared the rover to drive out to the ALSEP site and saw that the rear steering was now working. He drove out to the the ALSEP site, passing the 2 m boulder, and then turned to a heading slightly north of west (Figure 267) to create tracks which would serve as a guide for the geophone line. This was supposed to be a straight line but he had to deviate from it a little to the south as he passed craters about half way out. Then he turned sharply around a rock and back onto his tracks to return. Back at the ALSEP he turned south and parked out of the way for ALSEP deployment, which Duke had already begun. Figure 267 is modified from Figure 6-13 of Muehlberger *et al.* (1972). This map includes information from surface and orbital photography.

Duke laid out the Heat Flow Experiment (HFE) electronics package and had to move it to avoid a small crater which would make it hard to keep it level, a common problem here. One of the probes would be close to a larger crater, about 5 m across, and he asked about relocating it and then did so. John was looking for Double Spot again, trying to ascertain his landing point. Meanwhile the TV camera on the rover was rotating to take a panorama, which was photographed in sections with Polaroid instant-print cameras on the ground to give the back-room scientists a hardcopy panorama. Duke returned to the LRV to collect the drill and Young struggled with the stiff cable connecting the RTG to the Central Station.

Duke returned to the HFE and set up the drill on its tripod to drill a sensor hole. He began drilling and the bit cut into the soil easily until it reached a depth of about 30 cm. Then it slowed, probably because it had hit a buried rock, but it soon cut through or bypassed it and speeded up again. As Young set out the Passive Seismic Experiment (PSE) Duke removed the drill from the stem and added another section. He continued drilling until this stem was also well into the ground, hitting and bypassing another rock on the way. He added a third drill stem and it went down quickly. Young started to lay out the geophone thumper cable, getting the thumper itself tangled in it, as Duke used a rod to ram a heat flow sensor down into the drill tube. Everything was going well so far, but now a simple accident ruined the HFE. Young was taking the geophone mortar package from the Central Station to place it on its base, which was already deployed. He turned and his feet caught on cables, pulling one taut and then breaking its connection to the Central Station. He freed his feet and examined the damage. The cable used to transmit power and data between the HFE and the Central Station was broken at its connection to the Central Station and there was no obvious way to repair it.

As people on the ground began looking for a possible solution Duke decided not to drill the second HFE probe hole, and prepared to drill the deep sample core. This was a four-stem core which would reach 2.4 m deep, and the first stem went in very easily. As he tried to remove the drill and attach the second stem, falling over in the process, Young set the magnetometer down out of the way to work on setting up the Central Station. Duke finished drilling all four stems of the core tube and began preparing to remove it. He found this much easier than the Apollo 15 experience, partly because the cores had been redesigned and partly because he had a jack to help raise the core. He ran to the rover to collect the jack, noting that his feet sank in the soft regolith around a small crater. Meanwhile Young aimed the Central Station antenna towards Earth and then switched on the power to the connected experiments.

Duke installed the jack on the drill core and operated it with a treadle to raise the core, which came out of the ground easily. Young deployed the magnetometer on the only level area available to him, which was about 1 m from a rock, hoping it would not interfere with measurements. The scientists in Houston briefly considered moving it but changed their minds and let Young leave it where it was. Duke discarded the treadle, throwing it off to the south. He was asked to measure the depth of the deep core hole with the rod used to ram the heat flow probe into its hole, and then told he might place the second heat flow probe in the hole and see how far down it would go. This would serve no purpose and anyway Duke said it would not reach so the idea was abandoned. Houston had not yet completely given up on the HFE and Duke said he would like to keep the probe in case it could be used later.

Duke capped the deep core as Young finished leveling the magnetometer. Duke now placed the rammer rod in the deep core hole and it fell in almost to the full depth, showing that the walls of the core had not collapsed when the core was removed. This was a test of an idea for placing a neutron flux probe in the deep core hole on Apollo 17. Then he tried to pick up an interesting rock, kneeling down but having trouble getting back up. When he had it he showed it to the scientists back in Houston via the TV camera, and tried to clean dust off its surface. Tony England advised him to blow on it, a joke used several times in Apollo EVAs.

Attention now shifted to the geophone and thumper, which would be similar to the Apollo 14 experiment. Young had driven the LRV out to the west to leave tracks to guide the geophone deployment (Figure 267). Now he prepared the equipment for it and as Duke walked over to help him he disturbed the soft regolith on a crater rim which he had noted earlier. Now he observed a very white layer of regolith under the immediate surface, probably South Ray ejecta buried by a thin layer of locally derived younger ejecta. He forgot to bring a camera to document the geophone line deployment, so its exact position is uncertain.

Young pushed the anchor into the ground to secure the end of the line and warned Duke not to disturb the cables to the mortar. The cables were a constant problem and the recent HFE accident had the crew very concerned. Duke pushed a stake for the first geophone into the regolith nearby and noted how easily it went in, suggesting they should modify a later experiment with a penetrometer on EVA 2 to suit the soft regolith here. Next, he pushed the geophone itself into the surface. Young walked to the west, paralleling the LRV tracks and laying the geophone line down behind him. Duke followed him, deciding again not to collect the camera. They passed over a low rise and descended again, checking that the first geophone stake was still upright, a sign that they had not pulled the line enough to disturb the geophone itself.

At 45 m from the first geophone Duke emplaced the second one, anchored it and set up the stake which marked its position. As Young walked further out, descending on the sloping surface until he could barely be seen by the TV camera on the rover, Duke returned to the LRV and collected his camera. He noticed a purge valve locking pin from Young's suit which had fallen out at the rover, picked it up and put it on Young's seat. He took several images to document the ALSEP deployment including one looking straight down the geophone line, and later took a panoramic sequence of images. Young had now deployed the third geophone and began to use the thumper to set off a series of seismic signals for the geophones. The thumper was fired at roughly 4.5 m intervals along the geophone line, giving data to reveal the subsurface structure. Around this time TV coverage was lost for 4 minutes due to a communication problem at the Madrid communication station.

Young continued firing the thumper at intervals, after a ten second period each time when the astronauts had to stand still to avoid making their own signals with each step. Duke was asked to inspect the broken connector on the Heat Flow cable and knelt down to look at it. He described the break. In Houston a team including backup Commander Fred Haise worked out a possible repair, but it would have taken too much time out of the geology traverses and was dropped from consideration. Looking towards Smoky Mountain (called 'Smoky Mountains' on maps but not always made plural in crew descriptions) he noted large blocks on the slopes facing North Ray crater.

Young passed the second geophone on his way back to the ALSEP. Some Apollo 14 thumper firings failed, but these were all successful. Duke was now at the magnetometer and noted that he could not deploy its sunshade because one arm of the instrument was not properly locked in place. He was told to leave it but fixed it just as that advice was given. Young had now completed the thumper firings and discarded the thumper north of the geophone line. He cleared some packaging material away from the ALSEP area while Duke showed the scientists in Houston a glass ball he had picked up. Then he took the pin from Young's PLSS purge valve and reinserted it. Young speculated that he had lost it when he took off his seatbelt at the ALSEP.

The mortar which would fire charges for the geophone experiment after they had left the surface had to sit on a carefully aligned base unit. Young now set it up pointing parallel to the geophone line and levelled it as much as possible, though he could not deploy one of its four anchor stakes properly. He erected an antenna by which the mortar could be fired on command from Earth. More details of the mortar firings are given below.

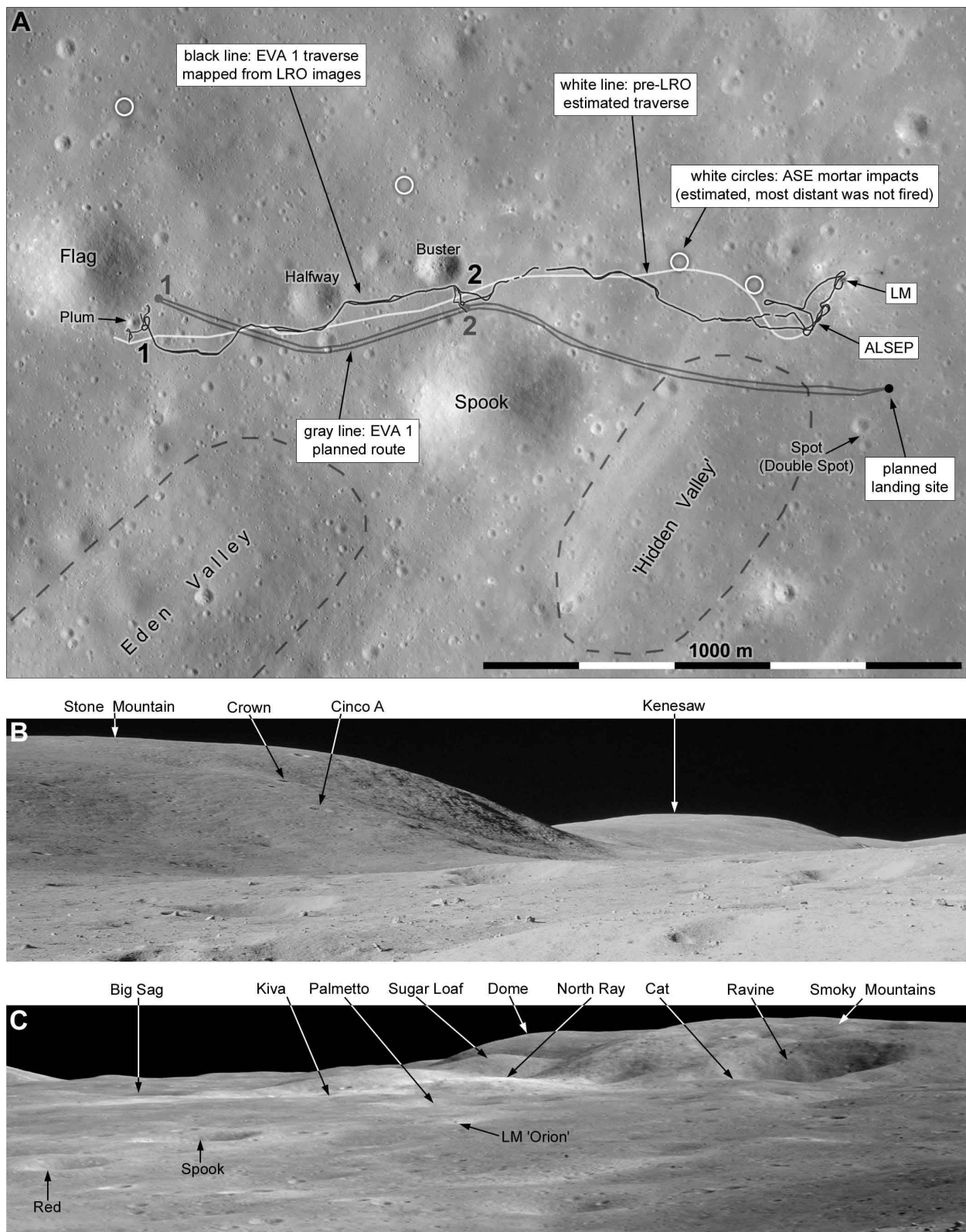


Figure 268. Apollo 16 EVA 1 and the Descartes Mountains. A: EVA 1 planned and actual traverses. B: Stone Mountain (image AS16-113-18326). C: Smoky Mountains (image AS16-107-17471).

As Young worked on the mortar Duke was at the rover separating sections of the deep core and capping them, after which he began collecting some nearby rocks and white regolith from the small crater rim. Young photographed the mortar and then joined him, pushing a rock with his foot to roll it a few metres. He helped bag a sample of white soil which Duke had collected, resting it on the camera strapped to his chest as if it were a table. Before they could set off on a geology traverse they needed to clean the cameras, now very dusty, change the film magazines and organize equipment on the rover. Young noted that the large rock near the rover was a breccia, as were most rocks here.

Duke pointed out an area just to their east where they could do the Grand Prix, a figure-8 driving and steering test like that done on Apollo 15. They looked at the mountains to the north and south of them, observing how close they appeared without familiar terrestrial distance cues. Then they climbed onto the rover and set off to the west. They had an automatic 16 mm camera to record the drive, and Duke would also take pictures at roughly 50 m intervals in case the camera failed as it did on Apollo 15. As they drove they described features they were passing, as noted on the EVA maps, which also helped locate them. In general the Apollo 16 tracks are more visible than Apollo 15's had been in LROC images, so the EVA maps here are more reliable.

Duke reported to Capcom Tony England "Tony, we seem to be riding across a ridge top that trends east-west. Off to the left, it drops off drastically ... into a valley which is probably Hidden Valley". That name is not shown on any Apollo 16 maps and clearly they are thinking of Eden Valley, but Eden Valley is southwest of Spook and would not be visible from here. From their description it seems they are mistaking a subdued depression east of Spook for Eden Valley, and this feature is labelled in Figure 268A as 'Hidden Valley'. They described rocks and could tell when they were in ray material from South Ray crater, but determining an exact location was difficult until they found Spook and Buster craters, partly because they were still uncertain about the exact landing site. One puzzle was the absence of small scarps or steep slopes which had been mapped before the flight on Apollo 14 images, based on misinterpretations by the geological mappers exacerbated by the albedo patterns of the South Ray rays.

Another problem they soon noted was difficulty driving down-sun, which was alleviated by tacking northwest and southwest, though they did not do this as much as the Apollo 15 crew had done on their EVA 3. Soon after passing Spook they encountered Halfway crater, mistook it for Flag and thought that a small crater south of Halfway was Plum crater. They stopped and stepped off the rover, but England soon advised them that they were only at Halfway and they should continue driving west. When they climbed back onto the rover Young noticed that his purge pin had been pulled out again by the seatbelt as he took it off. He retrieved it again.

Young drove south of Halfway and west towards Flag crater, through a ray which was very obvious to them because of the increased number of rocks on the surface. He tacked southwest and northwest through this area to improve visibility, and soon saw Plum and Flag craters, the area for Station 1 activities. The LRV was parked facing south, near the rim of Flag crater just east of Plum after Young looped around to try to match the parking instructions on his checklist (Figure 280). He stopped closer to Plum than was planned but the difference was not important.

Duke took a panorama on the rim of Flag, excited by the dramatic topography of the crater, whose walls were steep enough to cast shadows and which concealed the crater floor from Duke's view. He tried to look further down and England warned him not to fall in, so he continued describing the scene while Young worked to align the high gain antenna and start the TV. When the TV transmission started the astronauts collected a rake sample north of the rover on the rim of Flag. Duke pulled the rake through the regolith and shook it to remove fine material, but many of the small rock chips were too small to stay in the rake. They used three rake swaths to collect enough rocks for the sample and set about collecting other samples between here and the rover.

The TV camera, controlled from Houston, had found a rock with a white patch on it, and England now directed the crew's attention to it by asking them to look where the camera was pointing. This was on the eastern rim of Plum, but before working on it both astronauts moved onto the crater rim, collecting more samples and heading towards a partly buried boulder on the other side of the crater. Duke pointed out that Young was kicking up white soil on the crater rim from under a darker surface layer, and dug a trench to examine and sample it. Then they walked clockwise around the rim of Plum crater, again noting in response to a question from Houston that they did not see any scarps crossing the traverse route.

The partly buried boulder was their next sampling site (Figure 280). Young broke a fragment off the rock with his hammer and described it for the geologists on Earth before putting it in a sample bag. Duke noted that the white subsurface layer was also present here, and collected a sample from the fillet of regolith around the rock. Young took a panorama nearby and Duke photographed lineations created by shadows on the surface. Then they picked up an angular rock too large to fit in a sample bag and carried it back to the LRV.

Young dropped his hammer and they retrieved it, and when they returned to the rover they were asked to pick up the rock previously noted by England. It was a nearly 12 kg rock, the largest collected by any Apollo crew, later given the name Big Muley. Picking it up was not easy, and Duke said "If I fall into Plum crater getting this rock, Muehlberger has had it", referring to William Muehlberger of the University of Texas at Austin, the leader of the Apollo 16 geology team. 'Big Muley' is a play on his name. Eventually the rock was stowed on the rover and the crew departed, driving back along their tracks towards Spook crater.

The crew were running more than 20 minutes late at this point and Duke was using the water in his suit faster than expected, so the next stop, Station 2, was shortened from nearly an hour to about 25 minutes. England described the plans for the stop to them. There was some confusion about the identities of the craters here, but eventually they turned south off their tracks, made a small loop and parked facing south near the rim of Spook (Figure 280). Young's hammer caught on the rover instrument panel and he put it down on the seat to keep it safe as Duke noted that Young had lost his purge pin again and replaced it for him.

Young oriented the high gain antenna to allow TV transmissions while Duke observed the site, noting that the local blocks were clearly ejected from Buster and did not reach all the way to Spook. Duke then took a panorama and pointed out the LM to Young. Only the top of the LM was visible in the rolling terrain. Young cleaned the dusty TV lens to improve the picture and then set out the magnetometer to measure the local magnetic field. It was attached by a cable to the LRV and was carried out to a good location and supported on a tripod for its measurement, then controlled from a box on the rover. Young dropped the sensor and picked it up to deploy it, then returned to the LRV to operate it remotely, so neither he nor the rover would interfere with the reading. After taking the first reading he went back to the sensor, rotated it and returned to the rover again to take a second reading. He photographed the magnetometer so the scientists could locate it accurately. Then the magnetometer was turned again for a third reading.

Duke used a 500 mm telephoto lens to take pictures of Stone Mountain and South Ray. There had been concern that astronauts would not be able to hold the camera steady for clear photography with this lens, but the Apollo 15 experience had been very good. For Apollo 16 the results were generally poor, with relatively few high quality frames. Then Duke ran north to the rim of Buster, photographed its rock-covered floor and described the scene. He collected rock and soil samples quickly, at one point dropping his sample bags while holding a rock sample. Young had now finished the magnetometer readings and walked over to pick the bags up. He restowed the magnetometer on the rover as Duke bagged the sample, a fragile rock which broke in his hands. Then they climbed onto the rover and departed.

Duke had taken photographs from the rover on the westward drive earlier, and took more now, though he had not taken any between Station 1 and Station 2. They followed their tracks fairly closely and could see the LM for most of the way back. Driving towards the Sun was generally easier than driving away from it and they commented on the experience, like driving on snow (though Young had little experience of that having grown up in Florida). Soon they were back near the ALSEP where Duke dismounted and took the 16 mm camera off the rover to film Young driving the 'Grand Prix'. Young drove northeast towards the LM, turned counterclockwise, throwing up large 'rooster-tails' of dust behind each wheel, and drove back to the southwest, then turned again and repeated the sequence.

After the Grand Prix Duke collected the deep core stems he had left at the ALSEP, helped Young undo his seatbelt on the rover, and carried the core stems back to the LM. Young removed pins from the mortar to arm each charge and then drove the LRV back to the LM. Duke set up the Solar Wind Collector near the LM (Figure 266) and collected another rock sample, a piece of anorthosite. He documented the location and condition of the SWC with photographs and looked at the cosmic ray detector on the LM near the east-facing (rear) landing leg. It was heating up in the sunlight and Duke was told it had to be moved to the south footpad. Young moved it and turned it away from the Sun.

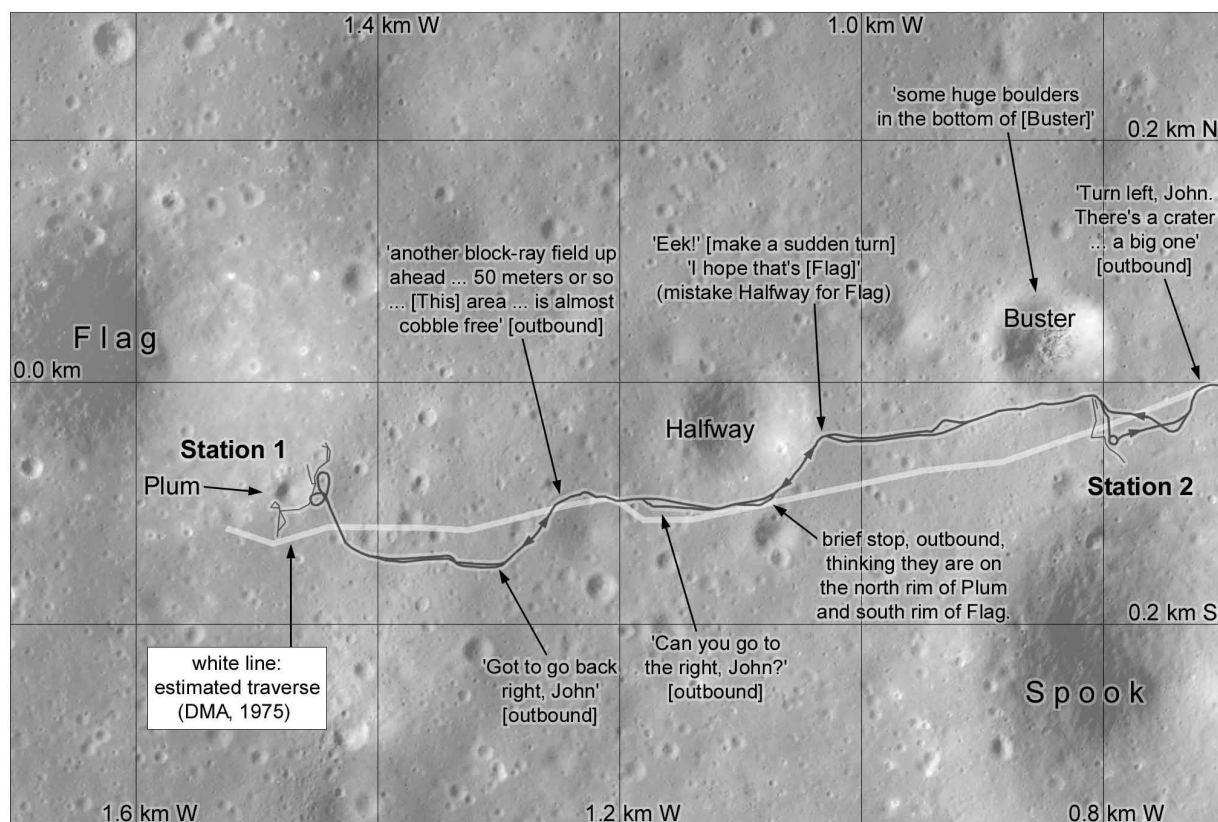
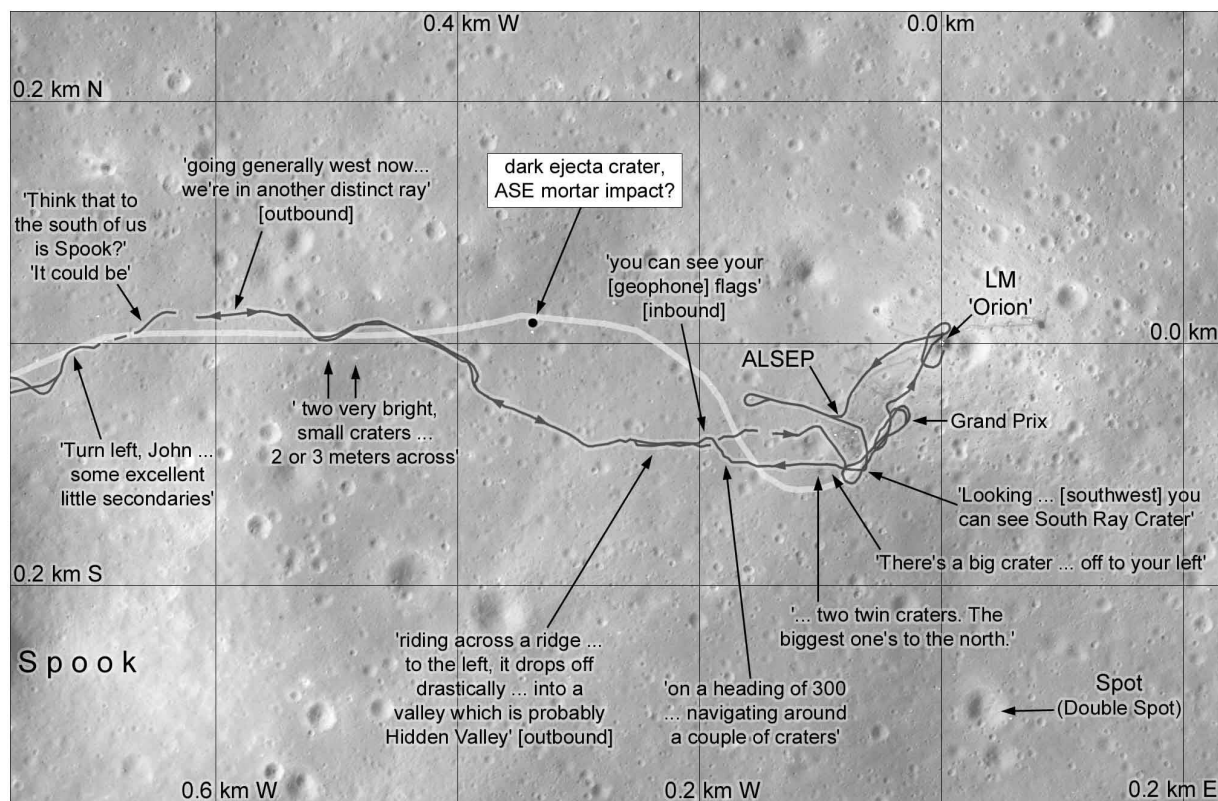


Figure 269. Apollo 16 EVA 1.

The astronauts worked to stow their samples, and Young dusted the TV camera again and reoriented the UV telescope for a new observation. It was becoming harder to turn and had to be relevelled after each repointing. He photographed it as Duke packed the equipment transfer bag, then put his camera in the bag. Food packs and other items stored in the Descent Stage were also transferred up into the cabin now. They worked hard to clean dust off each other to reduce the amount tracked into the LM cabin, and at one point dropped the brush they were using. Young tried to pick it up and fell over, but soon recovered both the brush and his balance.

Duke climbed up the ladder, taking a pallet containing samples and equipment from Young and carrying it further up onto the porch and then into the cabin. He emptied it and passed it back out to Young, who had climbed up to take it from him. Young filled it with more items, and reset the UV telescope again at an orientation radioed up from Houston. It was looking at the LM, so Young asked for a different target and pointed the telescope accordingly. Then he climbed up to the cabin and entered it, both astronauts struggling to fit into the cramped space with all their equipment. They pressurized the cabin and checked the LM systems before removing their helmets and gloves. Young, who had been unable to reach his drink straw inside his suit, took a very welcome drink as soon as he could get to it.

The two PLSS units were recharged ready for the second EVA while the astronauts were still wearing them. Apollo 14 astronaut Ed Mitchell was now Capcom in Houston, and he joked about sending Young and Duke outside again right away. They commented frequently about the ubiquitous dust and about how tired their fingers were from gripping things in their gloves. The PLSS units were taken off and stowed, and they weighed their sample containers to help plan the eventual liftoff when total spacecraft mass would have to be known. England, back on duty as Capcom, let the crew know that Ken Mattingly in the orbiting CSM was collecting good orbital data from the science instruments in the Service Module, though the laser altimeter was sometimes missing readings.

Young and Duke took off their suits and tried to clean themselves and any seals and zippers which were affected by dust, noting a gunpowder-like smell from dust in the air. Houston sent up lists of changes to procedures and plans for the upcoming EVAs, and asked Duke about a black rock under the LM engine which he had called a vesicular basalt, an unexpected rock type for this area, leading into a detailed description of the geology of the landing site and individual samples. They had a meal and soon began an 8 hour sleep period.

When the astronauts woke up they reported to Houston on their meals and sleep. The team in Houston were still thinking about repairs to the Heat Flow Experiment and they discussed whether the Central Station could be moved or tilted without disturbing the seismometer. Then Capcom Tony England discussed plans for EVA 2.

Ken Mattingly had reported several benches or terraces in Stone Mountain and layers in the walls of South Ray. Stations 4, 5 and 6 would sample two different terraces on the mountain and its base, and rays at Station 8 might include material from different layers in South Ray. They would not go as far south as Crown crater because it looked older than the Cinco craters, so Station 4 would be near Cinco d and Cinco e craters (Figure 270). Station 7 would be omitted to give more time to sample at Station 10 near the LM. While driving between Stations 6 and 8 they should keep the 16 mm camera pointed into Stubby crater, not looking forwards as previously planned, since the view to the west would be washed out by the down-Sun illumination. Station 9 would be between rays and the crew could decide a suitable location. Station 10 would examine ray and non-ray surfaces.

Young asked about moving the UV camera to keep it shaded, but communications became difficult for a while due to problems at the Honeysuckle Creek antenna near Canberra in Australia. They had breakfast, and then took numbers from Houston for emergency take-off times on each orbit of the CSM to enable a rendezvous, something they did several times during their stay on the Moon. They also had to check the measure of time used throughout the flight, Ground Elapsed Time (GET). Houston had updated GET for itself and the CSM during preparations for EVA 1, but the LM clock had not been updated yet. The change was caused by the landing delay which caused the CSM to switch to its mapping orbit later than planned, so the SIM Bay photography timing no longer matched the plan exactly. LM time would not be changed until shortly before liftoff.

Young's purge valve locking pin had been pulled out three times on EVA 1 when his LRV seatbelt caught on it, and Houston now suggested they attach a cord to it and to the suit so the pin would not be lost. The communication difficulties continued sporadically while they prepared to dress for the EVA. England was able to pass on

preliminary results from the X-Ray Fluorescence experiment in the CSM, showing that the Descartes area had more aluminium relative to silicon than the mare areas, as expected, but the farside highlands had even more. Preparations continued with the donning of the PLSS units and communication checks.

Young made sure the drink bag in his suit was accessible for this EVA and then they donned their helmets. Duke's tool harness dropped off the suit and onto the floor and was difficult to pick up and put back on, slowing them down. They pressurized the suits and checked they held pressure. Then the cabin pressure was reduced through an overhead valve, and when everything was confirmed to be satisfactory the hatch was opened. The cabin floor was very dusty and the escaping air carried dust out, helping to clean the cabin.

Young bent down and moved through the hatch, guided by Duke. He threw a jettison bag of unwanted items down to the surface and then took an equipment bag containing cameras from Duke. He had to avoid the large rock 'Big Muley' (he called it 'Old Muley') which had been left on the footpad, and Houston gave him instructions for moving the UV telescope back into shadow so it would not overheat. It was in shadow during EVA 1 but the rising Sun had now reached it. Duke climbed down as he was doing this. The telescope was supposed to be moved closer to the LM body but Young found he could not work in the confined space and had to move it to the west, still in the shadow. He pointed it at Earth while Duke prepared the TV for transmission. From the azimuth reading on the instrument Houston could calculate the new pointing for other targets.

Duke loaded the LRV with equipment while Young pointed the telescope as instructed, but he found it was pointing at the LM. After the mission he expressed frustration at the amount of time dedicated to the telescope and the problems they had with pointing. When it was correctly pointed he checked that the cosmic ray experiment was properly deployed. Duke took a panorama north of the LM and Young was asked to pick up a rock, if possible the dark 'vesicular basalt' reported to be under the LM, but that was 'a double Muley', too large to bring back. Duke pointed out other potential samples for him, and then he photographed the cosmic ray experiment to document it.

Young now pointed the UV telescope again, this time towards Stone Mountain to look for volcanic gases which might be seeping from the mountain if, as suspected at the time, it had been a volcanic mound. Then they mounted the LRV and set off for Stone Mountain with the 16 mm camera running and Duke taking photographs along the route. They described the rocks, often black and white, which they were passing and the view from their elevated position across Survey Ridge to Stone Mountain. They passed Double Spot, mistaking one of the two craters for WC, and soon after the rear wheels skidded sideways, probably as Young tried to avoid an obstacle. Duke said "Yeow, Whooo Man, that was a great big skid!" and the LROC images show a spray of darkened regolith at this location (Figure 271).

They slowed down through a rough area, describing rocks along the traverse. Angular rocks had probably been thrown out of South Ray but rounded rocks were dustier and apparently older, possibly ejecta from North Ray or other craters in the vicinity. They passed a metre-sized breccia boulder and soon after climbed up onto Survey Ridge (Figure 272), swinging to the right to drive along its ray-covered and very blocky crest. The tracks here are almost invisible and the route in Figure 272 is based on inspection of Duke's Hasselblad images jointly with Brian McInall. It is the least certain part of the entire traverse.

Duke commented on a split boulder as they descended from the highest point of the ridge, and Young decided to turn south to leave the ridge as soon as he could to get away from the very rocky ray. Dropping into a valley between Survey Ridge and Stone Mountain, they felt a severe jolt as the LRV crossed a small crater, but the rover could handle the rough conditions and soon they were climbing up the lower slope of Stone Mountain. The views out to the west became spectacular as they climbed higher, looking out over the very bright rim of South Ray and the smaller but similar Baby Ray.

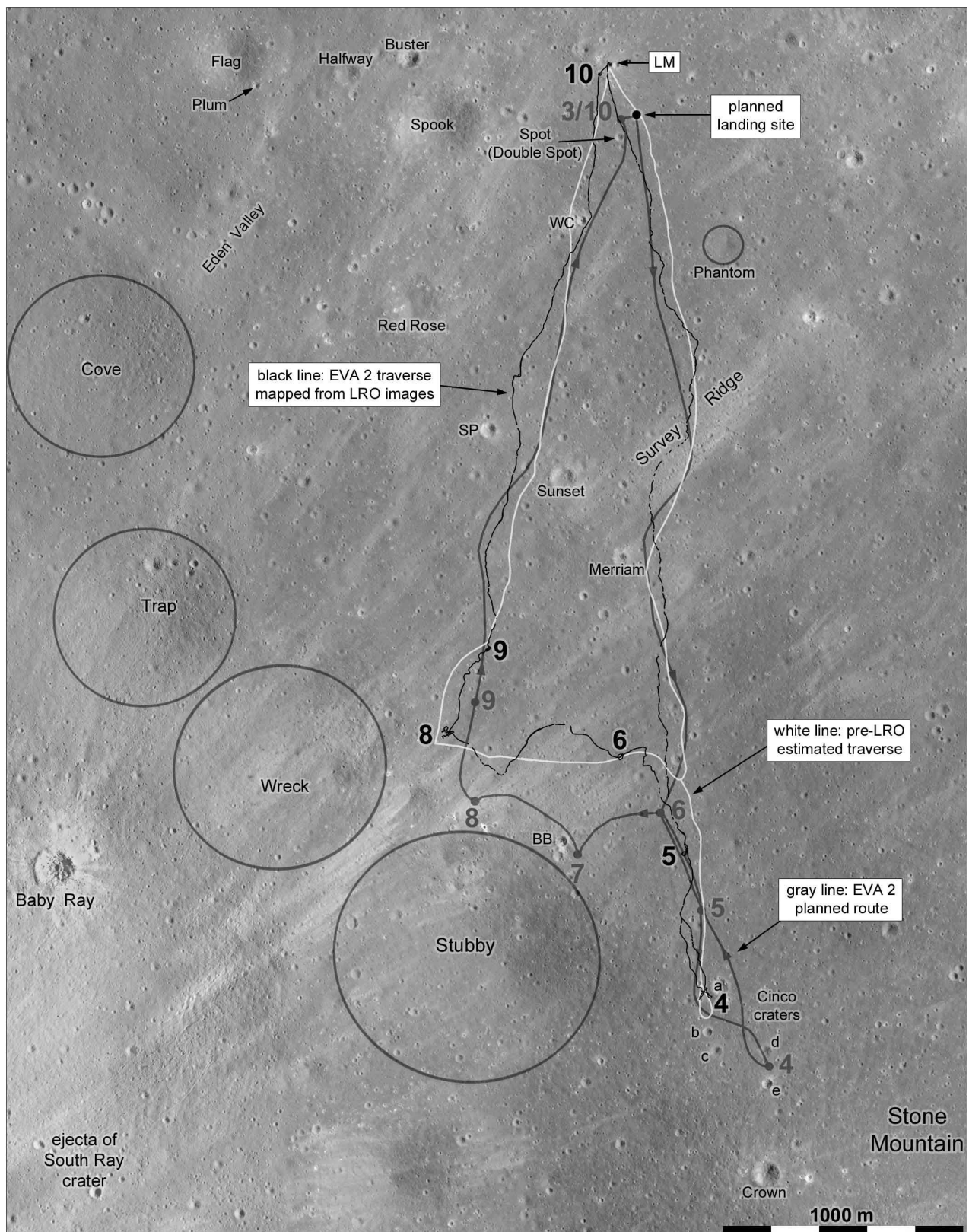


Figure 270. Apollo 16 EVA 2, context map.

Duke looked out for a crater fresh enough to have cut through South Ray ejecta and into the rock of the mountain, offering the best chance to guarantee a sample of the Descartes Formation, the material of the hills and mountains south, east and north of the landing site. Soon they were among small craters in the Cinco group, but thought they were further south near Crown and looked for a place to park. Young looped around and returned to a roughly level parking spot on the northern wall of a subdued crater just west of Cinco a (Figures 270, 273, 280). Mattingly was orbiting above them at this moment and thought he saw a flash of light as if reflected off the LRV.

Duke dismounted and looked round, saying he could see the LM and the large boulder later called House Rock at Station 12 (Figure 279) on the rim of North Ray crater. He aligned the high gain antenna to permit TV transmission and then began to take pictures with the 500 mm telephoto lens, starting with views of South Ray. He moved on to Baby Ray, the subdued crater Stubby and then the LM area and North Ray, which was barely visible as the crater tilted down to the north and the interior was hidden behind its southern rim, like the crater Cone at the Apollo 14 site. North Ray had formed on the northern slope of a hill shown in Figure 279 as North Ray Ridge. Many of these images were blurred or of very low contrast and were not very useful.

Young was looking for samples and when Duke described South Ray as having both light and dark rays he agreed. The TV camera, controlled by Ed Fendell in Houston, made a panoramic sweep around the site and on Earth the TV pictures were photographed using Polaroid instant print cameras so the geologists could work with them or target further observations. Duke put the 500 mm camera on the rover and took the rake, noting that one of the back wheels was off the ground on the uneven terrain, and then dusted the TV lens while Young collected a rock sample. Duke took a rake sample nearby (Figure 280) and then a bulk sample of the regolith as Young held the sample bags.

They returned to the LRV and Duke picked up the penetrometer, a device to measure soil mechanical properties as it was pushed into the regolith. Young collected samples including impact glass as Duke assembled the penetrometer, dropping part of it and using tongs to pick it up. Then Duke used the penetrometer at several locations around the crater they were parked in and Young continued bagging rock samples. Duke suggested that these were all South Ray rocks rather than samples of Stone Mountain and wondered if they could find a crater with mountain material in its ejecta, perhaps the 20 m diameter crater just north of them which he was approaching now. He took a last penetrometer reading, falling over as the instrument was pushed fully into the soft regolith and quickly pushing himself up again.

Meanwhile Young dug a trench in the subdued crater's floor to see if there was darker material below the bright surface, but there was not. He sampled the trench floor while Duke prepared to take a double core below the rover where he suspected the mountain material might be found. Young thought the rocks here looked like those near the LM, and when England asked if there was a rocky-rimmed crater nearby he suggested the one uphill from the rover. He walked up to it. The intention again was to find mountain rock samples rather than South Ray ejecta. The entire eastern wall of this crater was plastered with rocks which almost certainly came from South Ray, so Young looked at the western rim. He took a panorama from this location but doubted if he could find local material here.

Duke collected his double core easily, pushing it in at first and then hammering. England thought that the harder subsurface might be the local regolith of the mountain under the later ejecta layer. Duke pulled the core out of the ground and returned to the rover to cap and store it. Young suggested climbing into the crater he was standing at but England suggested instead that Duke bring the rake up and they sample the rim with it. As Duke finished stowing the core Young collected a bag of regolith from the crater rim, and then looking round he realized that the LM had landed north of Double Spot, accurately placing it for the first time.

Duke came up the hill with the rake and Young took it from him and raked up a sample on the crater rim. While this was happening the backroom scientists and Apollo 13 astronaut Jim Lovell were planning Station 5 activities and the team at Houston had finally decided to give up on any attempt to repair the Heat Flow Experiment. The astronauts returned to the rover and Duke took a second panorama nearby, and then mounted the rover to head downhill to Station 5. This was to be a primary impact crater dug into the Descartes Formation rocks of the mountain, where samples of unequivocal mountain rock would be available. The crew would choose the Station 5 crater themselves as they approached the area.

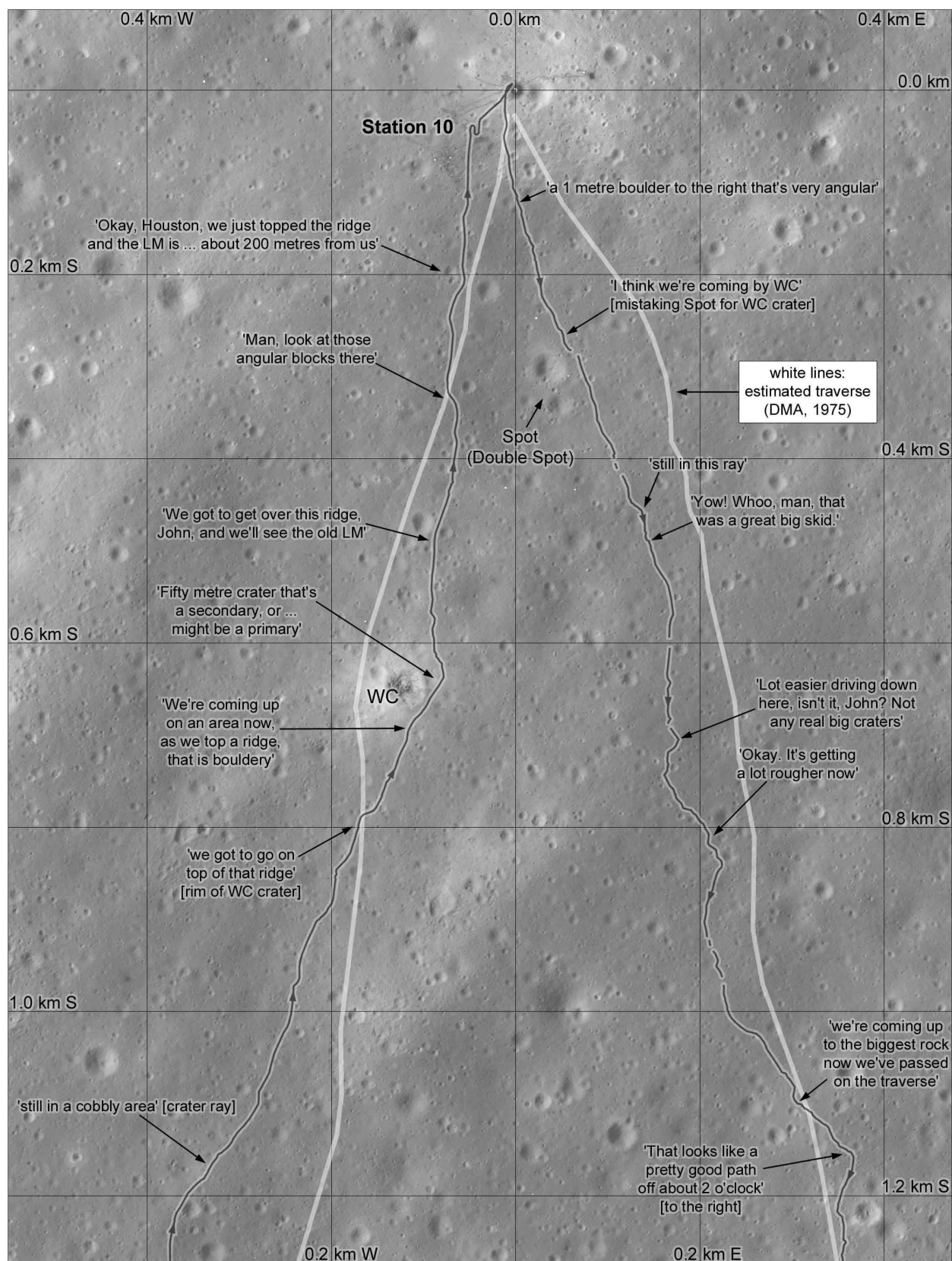


Figure 271. Apollo 16 EVA 2, map 1.

Young drove the rover downhill while Duke took pictures along the route. The 16 mm camera was not used for this short drive because a setting was not correct and they could not adjust it while moving. The rover was allowed to run without power once they got started, and had to have the brake applied lightly to stop it accelerating dangerously on the slope. They had driven northwards to the east of the uphill (outbound) path but soon encountered their tracks and followed them. Young said "Charlie, you said you were going to see some other tracks on the Moon", referring to a dream Duke had described before the flight in which they encountered tracks as they drove to North Ray.

The rover skidded at one point but Young recovered control and they soon saw a suitable crater for Station 5. Sanchez (1981) mapped Station 5 at another similar crater about 100 m northeast of this site, and the Apollo Lunar Surface Journal identified another crater about 120 m south of the real location (Figure 273), but Stooke (2007) identified it as shown here by observing another crater due west of it in the panorama. They approached just to the east of their uphill tracks and looped around to park facing southwards on the crater rim, now just west of the old tracks (Figure 280). They dismounted, but Duke was on the downhill side dropping into the crater and would have trouble climbing back on later, so Young suggested they move the rover. They manually shifted it sideways about 2 m, roughly the width of the rover, onto the uphill tracks where the surface was more level. Young oriented the antenna and the TV transmission started.

As Young brushed dust off parts of the rover to stop them heating up in the strong sunlight, Duke took a panorama nearby. They both looked at South Ray, noting large black and white rocks, and Duke said he thought they could reach it if asked though that had not been considered in planning. Young took the rake and walked out to collect a sample, noting a glass-spattered little crater as he went. He raked up a sample and filled a bag with it, noting it consisted of soil rather than rock fragments. He collected a second rake full of soil and bagged it. Each time Duke held the bag for him to fill.

Young now considered that he should rake from the western wall, the east-facing wall, of the Station 5 crater because it would be sheltered from deposition of South Ray debris. He walked over to that area, noting a glass-covered rock which Houston was asking for, and marked it with a prominent footprint so he could find it again. He used the rake to collect regolith but this time shook it to remove fine material and leave rock chips, and repeated the process to collect more. He and Duke switched roles and Duke made two more swaths with the rake to increase the number of rocks. They bagged the sample and Duke took another rake sample nearby.

At the southern rim of the crater, still working inside it, they found an old rounded and fractured rock which they thought was probably from the Descartes Formation. Duke took another rake full of regolith and shook it, having trouble keeping his balance on the steep slope of the crater wall. Then he used the scoop to pick up the rock which broke up when they tried to collect it, but they bagged it and then went looking for other rock and soil samples. Then they were asked to find a steep slope and dig into it as deeply as they could with the rake. Young did this, making at least 15 strokes with the rake and digging in about 30 cm. Then he dug in with the rake to collect a sample and shook it. There were no rocks in it. He raked through the pile of material dug out of the hole but still got no rocks, just clumps which quickly crumbled.

After a last few samples of regolith here they returned to the rover. Young was asked to take a measurement with the portable magnetometer. He carried it out to the west around the north side of the crater and took the measurement while Duke collected rocks near the rover. Young picked up a white rock, and soon stowed the magnetometer again, rolling up the cable. Duke put a new film in his camera, and they got onto the rover to head for Station 6. England asked them to choose a location with a rocky-rimmed crater on the lowest bench or terrace of the mountain.

Young followed his tracks for about 200 m as Duke watched for suitable craters. He first suggested a 40 m crater north of them, about 2.9 km south of the LM and 250 m east of it (Figure 273), but then told Young to turn to the west onto the bench at the base of the mountain. This path took them closer to the future Station 8. Duke spotted a crater with blocks and a less blocky alternative uphill from it, but England directed them to the blockier one. Young drove past it but looped back and parked facing south on its eastern rim.

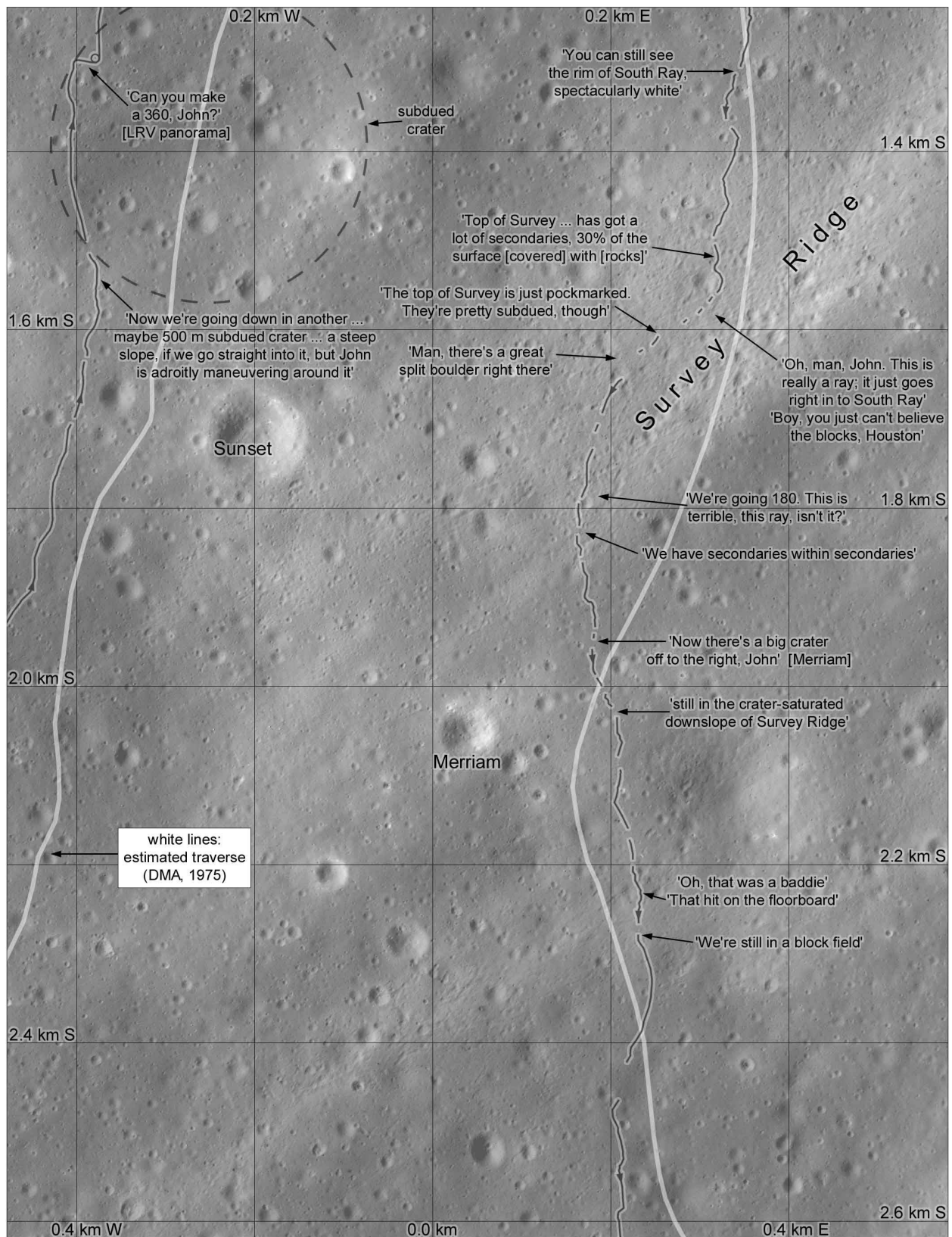


Figure 272. Apollo 16 EVA 2, map 2.

The regolith here was much firmer than the loose surface up on the mountain. Young got the TV working and cleaned its lens while Duke looked at a rock nearby. Duke took a panorama just behind the rover before both astronauts worked on sampling with the rake. Young dug a trench but did not see any sign of soil layering. He scooped white soil from an area nearby and Duke bagged it. They took samples from two larger rocks and then returned to the rover to begin the trek over to Station 8. One of the rocks collected here (66095) had unusual minerals associated with volatile elements and was later nicknamed Rusty Rock (Taylor *et al.*, 1973; Renggli and Klemme, 2021). Duke had trouble with his seatbelt, dismounted to fix it and fell over, and took a while to get settled before he was ready to move on.

To reach Station 8 they had to drive down-Sun, and Young tacked north and south significantly to improve visibility (Figures 273, 274). Tacking also improved stability as they moved across the sloping mountain base sideways with Duke on the downhill side. Jim Irwin on Apollo 15 had spoken about his feeling of insecurity in the same situation on Hadley Delta at Station 6a. The whole area was covered with blocks from South Ray and the terrain undulated significantly, sometimes dropping into a depression, sometimes climbing a ridge as they drove.

England wanted them to point the DAC 16mm camera into Stubby, but it was hidden behind local ridges. Their maps were compiled from fairly high Sun Apollo 14 photographs and were not good enough to show many of the smaller terrain features. England suggested they drive up onto the ridge if possible so they could see Stubby. They turned southwest and then south to climb the ridge but found the path was too steep, and Young noticed they had no power in the rear wheels. Later they found that a circuit breaker needed resetting, but for now it caused them to abandon the climb and turn northwest again. Young suggested they might have broken a wire as rocks struck the underside of the rover, but for now they could drive with power to the front wheels. They approached a group of rocks and chose this as their Station 8 (Figures 274, 280).

They dismounted and Duke immediately took a panorama near the rover and described the scene, including the distinctive large boulders, one rounded and dark, the other angular and white. Young collected a rake sample near the rover while Duke took a double core sample further to the west. His core hit a buried rock and would not go in far, so he pulled it out and shook it to remove the contents, then tried again a little further west. Hammering the core in was still difficult here but he persisted and got a full core which then came out easily. Young found an interesting piece of glass and collected it.

Young decided to move the rover closer to the large rocks they wanted to sample, and to check the rear wheels while he did so. He found that a switch was in the wrong position, probably accidentally knocked despite having a guard over it to protect it, and as soon as it was set correctly the rear drive was working again. Duke watched as he drove slowly around the rim of a subdued crater and parked about 15 m away from the first LRV location, before joining Duke at the large boulders.

The astronauts collected soil and rock samples at the darker boulder and then moved to the white boulder. Young hammered a fragment off it, looked carefully at it and described it as plagioclase. He collected some more fragments and they bagged them. The next task was to try to tip the rock over and sample underneath it. The freshly exposed regolith under the rock would be compared with samples taken nearby which had been exposed to solar wind and cosmic rays for longer. This large rock could not be moved and a second rock nearby also would not tip over. They moved over to a rock east of the rover and worked on that instead.

They collected a rock chip from the hard boulder, but they could not tip it over. Moving a few metres north they scooped a sample of undisturbed regolith and then moved west to try to tip a smaller rock, but Houston advised them not to bother. They spent a few extra minutes sampling and then loaded the rover for the drive to Station 9. As Young worked at the back of the rover he caught his leg on an extended section of the right rear fender and broke it off. They got into their seats and drove away, looping tightly round to head back north.

Station 9 was intended to be as free as possible of South Ray ejecta. It would be between rays and possibly, as Houston's backroom science team suggested, in a shallow depression. The plan was developed when people still expected to find scarps crossing the area, and one facing southeast might have sheltered the surface from any traces of LM exhaust. The scientists were seeking a sample as pristine as possible, lacking both recent ejecta and LM exhaust products. They found a possible location and maneuvered to get into a good position (Figure 281).

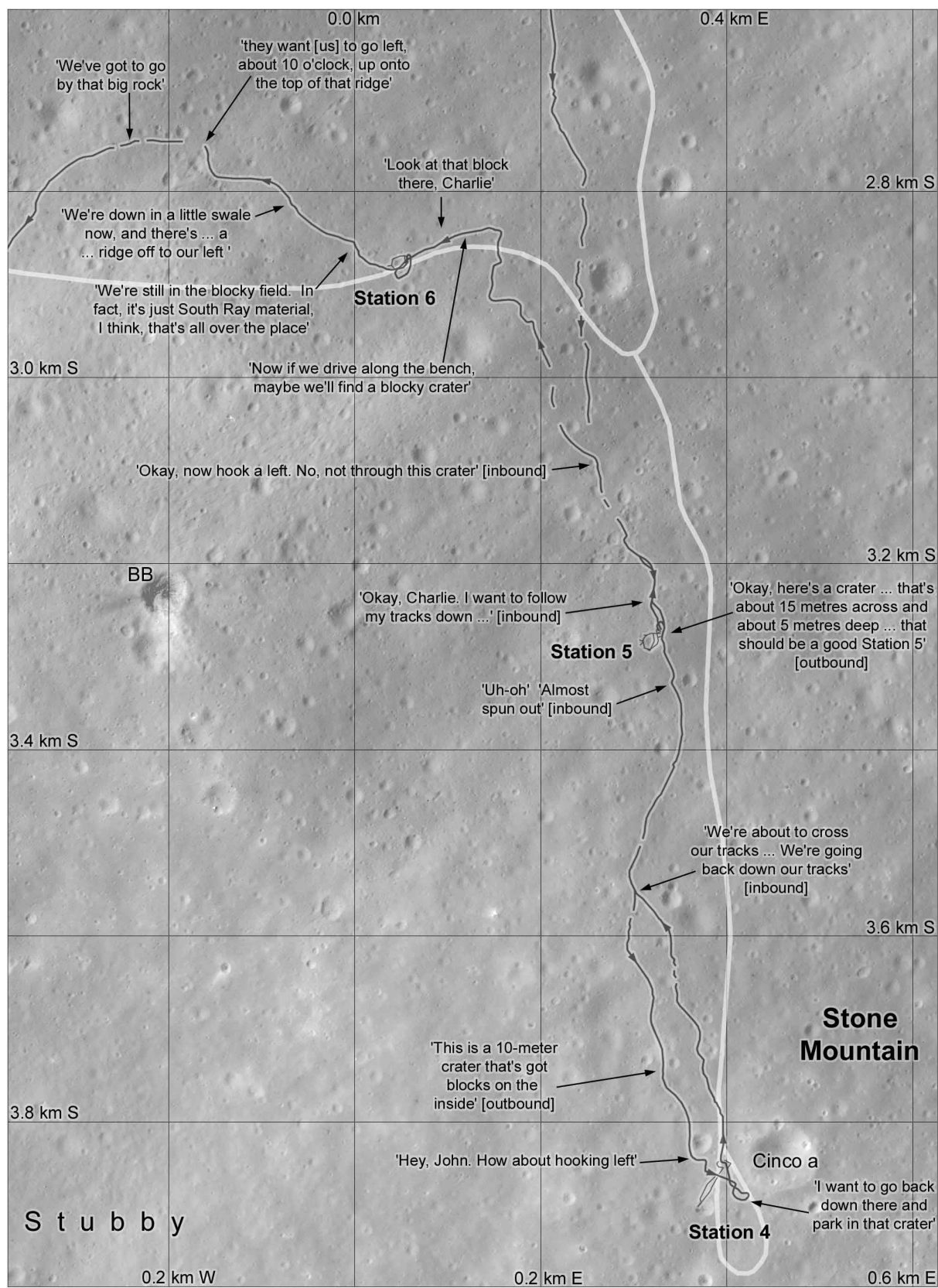


Figure 273. Apollo 16 EVA 2, map 3. Add St. 5 from Sanchez (1981).

Young started the TV, aligned the antenna and dusted the lens. Duke took a panorama of the station and then picked up the special tool for this special sample, the Contact Soil Sampling Device, which was a cloth pad pressed onto the surface so the topmost layer would adhere to it. There were two pads of different composition, used separately, and each one hinged so it could be closed on itself after sampling. Contamination could come from the LM, outgassing from the PLSS and regolith kicked up by the astronaut's feet on the way to the target. The strategy to minimize all of these was to find a rock whose southwest side would be sheltered from LM exhaust, to approach it carefully ('sneak up on it') to avoid kicking regolith onto it, and to bend over the rock and sample behind it.

Young crept up to the rock and collected the first contact sample, but it was not seen on the TV which was looking elsewhere until it was too late. He closed the sample pad and then collected the second contact sample. He observed that the rock they were bending over was not fixed and might serve the purpose not achieved at Station 8 of allowing sampling under a rock. They stowed the closed sampler pads and returned to the rock to scoop up a soil sample, and finding a hand tool they no longer needed Young threw it away to the southeast, seeing how far it would fly in lunar gravity. He said it flew right across a crater, somewhere to the southeast. Duke took two soil samples near the rock, one shallow, the other deeper.

Next Young chipped a sample off the rock they were working at, and dropped the set of bags he had hanging off his camera. He picked them up and put them on the rover while Duke began taking a core sample, a single core which would be placed in a special vacuum container to protect any volatiles from contamination on Earth. He stowed it at the rover as Young returned to the rock and pushed it over. Duke collected a sample of the compressed regolith under the rock, and then Young chipped a sample off the rock. They returned to the rover, stowed samples and changed films in their cameras before setting off.

Young looped the rover around and drove north as England described plans for Station 10 near the ALSEP. They would approach the ALSEP carefully, park nearby and bring the broken heat flow cable end to the TV camera for inspection. The Station 10 activities would be done northeast of the ALSEP. The 16 mm camera had not been turned on so coverage was missed early in the drive, but Duke took pictures himself during the drive. Young commented on the rolling terrain, much more uneven than their maps had suggested, and Duke mistook a local depression for Eden Valley (calling it 'Hidden Valley' again). He mentioned a broad depression ahead of them, shown on Figure 274, and Young veered a little to the west to avoid driving through its deeper parts.

The missing fender extension which Young had broken off at Station 8 had protected them from dust thrown out of the wire mesh wheel, and now they noted that they were being showered with dust. The rover's navigation system was not working now but they were heading in the right direction and had no problem finding the LM, which they could see as they crested each ridge. Young drove up out of the depression and soon encountered another one which he also skirted on its western side (upper left part of Figure 272). He avoided dropping into the bottoms of these depressions in case climbing out was difficult, and this one had several prominent crater obstacles in its centre. Duke said it reminded him of Big Sag, the depression shown in Figure 264, though it was much smaller.

As Duke described the craters in this depression England asked him to turn the 16 mm camera to view them. Duke could not move it so he asked Young to drive in a tight circle while he took pictures with his camera. The resulting half panorama (Figure 285A) showed Stone Mountain in the background and the broad depression with a broken foreground caused by rover motion. The tracks show the location clearly (Figure 272), and the technique was useful enough that they used it again in EVA 3. The Apollo 17 crew did the same thing several times. Only now, when England said that the 16 mm camera film should be finished and needed changing, did Duke realize it had not been running, and turned it on.

England now gave them revised plans for Station 10. The imaging of the Heat Flow cable would be dropped and the rover would park midway between the LM and ALSEP. A plan to dig a trench was also abandoned. They drove past the fresh, rocky-rimmed crater WC and soon after that, cresting a ridge, they saw the LM only 200 m away. Young approached the ALSEP on its eastern side and turned the rover to face south during the Station 10 activities.

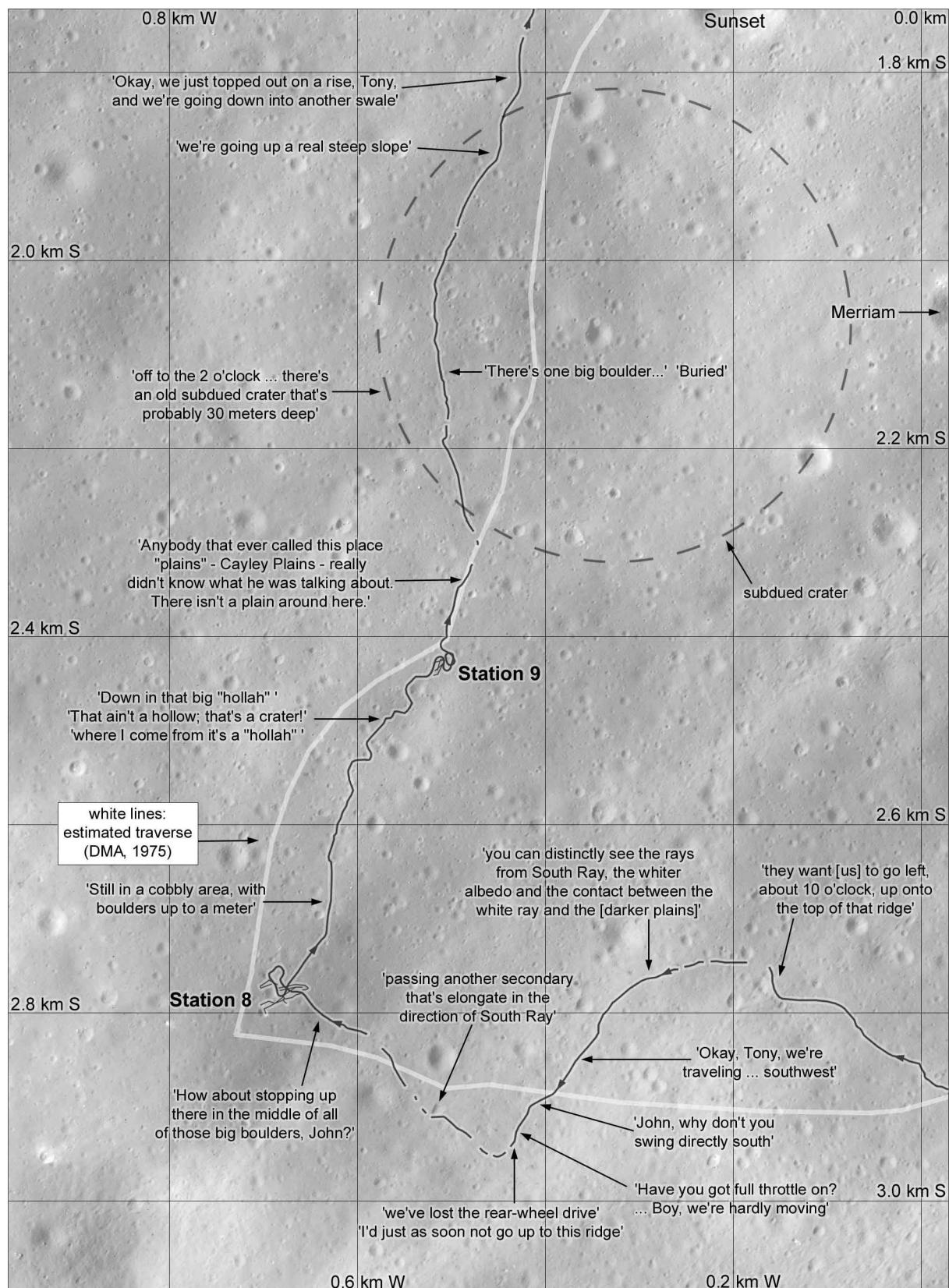


Figure 274. Apollo 16 EVA 2, map 4.

Duke immediately began preparing to collect a double core and both astronauts asked for the option to stay out a little longer on this EVA, hoping to break the Apollo 15 record EVA length of 7 hours, 12 minutes. The flight surgeon accepted the request as long as it would not shorten their sleep period. Young notices that a sample bag fell off his PLSS some time between leaving Station 9 and arriving at Station 10, but it had caught on the rover body and not been lost. Young was asked to use the penetrometer while Duke acquired the double core, but they decided to swap jobs because Duke knew the penetrometer process better than Young. The core was difficult to drive into the regolith despite hammering many times, and then quite difficult to pull out, but it was obtained successfully.

Duke made several penetrometer readings including one close to the double core site (Figure 266A) while Young capped and stowed the core tubes and then went looking for vesicular basalt, following a request from Houston. He could not find any and set about picking up other samples instead. They were asked to pack up and return to the LM, so Young quickly took a panorama from near the rover and drove the rover back to the LM. Duke ran back rather than climb onto the rover again for a 60 m drive. Young parked the rover close to the LM on its north side near the MESA and Duke looked at Stone Mountain, noting that he could not see their rover tracks on the slope. Young photographed the UV telescope to document its location, and then turned it away from its view of the sky just above Stone Mountain and towards a new target.

Duke loaded a sample box with cores, bags of rocks and soil and an unbagged rock. Food stored in the MESA was brought out to bring up to the cabin. Duke mounted the ladder and Young passed him a pallet containing the food and then pointed the UV telescope to another target, the geocorona, a glowing cloud of hydrogen ions around Earth. Duke unpacked the pallet in the cabin and passed it back down to Young, and also threw a small unwanted item out, but Young reminded him the UV telescope was close by and he should not do that. Young, on the LM porch, now pulled an equipment bag up on a lanyard and passed it through the hatch to Duke. He went back down the ladder for a sample box, brought it up and passed it in, then repeated the process for a second box. He entered the LM and they closed the hatch, having established a new EVA record of 7 hours 23 minutes.

Inside the LM the astronauts removed their suits, commenting again on the smell of gunpowder from the dust. The PLSS units were recharged and Houston passed some sports scores up to them. They noticed that the top of a small radio antenna on Young's PLSS had broken off during the awkward process of entering the small hatch, but it did not seem to affect communications. They weighed the sample containers and passed the weights to Houston, complained about the quantity of dust on the cabin floor, and tried to radio the CSM as it passed overhead. Mattingly was in the middle of a bistatic radar experiment and did not respond. Then Houston read out the emergency liftoff times for the next five orbits, and discussed the crew's geological observations on Stone Mountain. Young said "By golly, that view from up on Stone Mountain is something else" and the CapCom (Tony England) relayed the excitement among the geologists. A lengthy list of flight plan changes was read out to the crew, and then they prepared for their sleep period.

The astronauts were woken after a 7 hour sleep period, and as the bedding would not be needed again it was quickly packed into a jettison bag. Another set of emergency liftoff times was read up to them. They ate breakfast and began dressing for the last EVA, and Capcom England gave them an update on EVA plans. Stations 11 and 12 on the rim of North Ray would be combined into one stop and some photography would be cut to save time. The landing had been late but the liftoff would remain on schedule, and for that reason they had slept before EVA 1 and would not sleep after EVA 3. The third EVA was still possible if they shortened it. Station 13 would be done on the North Ray ejecta but other stops shown in Figure 249A would be dropped. Finally they would return to the LM area at a site called Station 10' (Ten Prime) for sampling and a double core. Figure 275 shows the planned EVA from MSC (1972) as a gray line. The EVA route estimated after the mission, shown in white, is taken from DMA (1975). A black line shows the actual traverse derived from LRO and surface images.

Young noted that the UV camera was partly sunlit again and would need to be moved back into the shadow. They continued preparations and checked through lists of actions and settings, and were ready to depressurize the cabin well ahead of schedule. They opened the hatch, threw out the heavy jettison bag, and then Young climbed down the ladder. England said "Out again on that sunny Descartes Plains" and Young replied "Ain't any 'plains' around here, Tony. I told you that yesterday", to which England retorted "Okay. The lumpy Descartes Plains". An equipment bag containing cameras was passed down. Young put it on the LRV and then walked over to move the UV camera fully into the LM shadow. As he moved it and pointed it at a new target Duke turned on the TV camera.

Duke used the camera with the 500 mm telephoto lens to take images of Stone Mountain from the LM area, though many of these frames were blurred. Young took a new battery for the rover from the MESA, but since the old battery was still good he stowed the new one under a seat. Duke took a panorama from a position west of the LM (Figure 266). Every picture shot on this film magazine had a smear on it made when they tried to wipe dust off the camera in the LM earlier. They prepared the rover for the drive to North Ray and Young reset the UV telescope, and moved its separate battery pack into the shade.

The rover navigation system had not worked during the last leg of the EVA 2 traverse, so in case it was not working well during EVA 3 Duke looked for landmarks to help them navigate back to the LM. He ran out north of the LM, turned and looked back to see what it should align with on Stone Mountain. He identified a line of three craters including Crown which would help him find the LM, and then the astronauts mounted the rover and drove away. The 16 mm camera was not operated for the first part of the drive to ensure it had enough film for the approach to North Ray, but Duke took pictures throughout the drive.

Young suggested that the ridge north of the LM would be a good vantage point from which the rover TV camera could watch the liftoff, rather than the planned position east of the LM, but the plan was not changed because the LM azimuth during ascent would be constant when viewed from the east. As they topped the ridge the North Ray area and Smoky Mountains came into view and Duke noted rocks extending from North Ray up onto the mountain. Coming down off the ridge on its northern side they approached a depression which they called a 'big sag-type area' and Young wondered if it was Palmetto (Figure 276). He drove around it on the eastern side, and another 'big depression' was noted about 600 m east of the 'big sag'.

They passed a large boulder surrounded by a fillet or bank of regolith, and climbed onto the rim of Palmetto, impressed by its size and the view to the east. Young skirted it on its eastern side and continued northwards while Duke gave a commentary on the boulders he could see on the rim and out as far as Ravine crater (Figure 275). They noted craters Dot and Cat, named after Duke's wife and sons Charles and Thomas, and Duke turned the 16 mm camera on here to record the rest of the traverse. As they approached the blocky-rimmed crater End Young turned to the east to find a smoother path, and they dropped quickly down into a low area northeast of Palmetto (Figure 277).

The surface now became smooth and block-free as Young drove northwards, and then rougher again as they approached the ejecta of North Ray. The crater was mostly hidden behind a foreground ridge but House Rock was sometimes visible. They bumped over a small sharp crater and turned to the northeast briefly, then curved back to the north and round to the northwest. Duke described a 'big sink' depression which was probably the subdued 200 m crater 3.4 km north of the LM (Figure 278), and a 'deep pit' between North Ray and Kiva, though it is not easy to match their descriptions with individual features. They picked a path up North Ray Ridge which avoided the most rock-strewn area and noted large boulders to their right where Station 13 would be located on the way back.

The surface flattened on top of North Ray Ridge and House Rock was clearly visible as they approached the crater rim. After climbing a final slope up to the rim they looped around to find a good parking spot and to face north, between a group of white boulders and the large dark boulder House Rock (Figures 279, 281). Young noted the steepness of North Ray's walls, too steep for them to see its floor. They set up the TV and Duke turned off the 16 mm camera, which had run out of film. The first task was photography, starting with a panorama taken by Young beside a 10 m crater 25 m north of the rover. The TV also swept out a panorama for the benefit of the geologists in Houston.

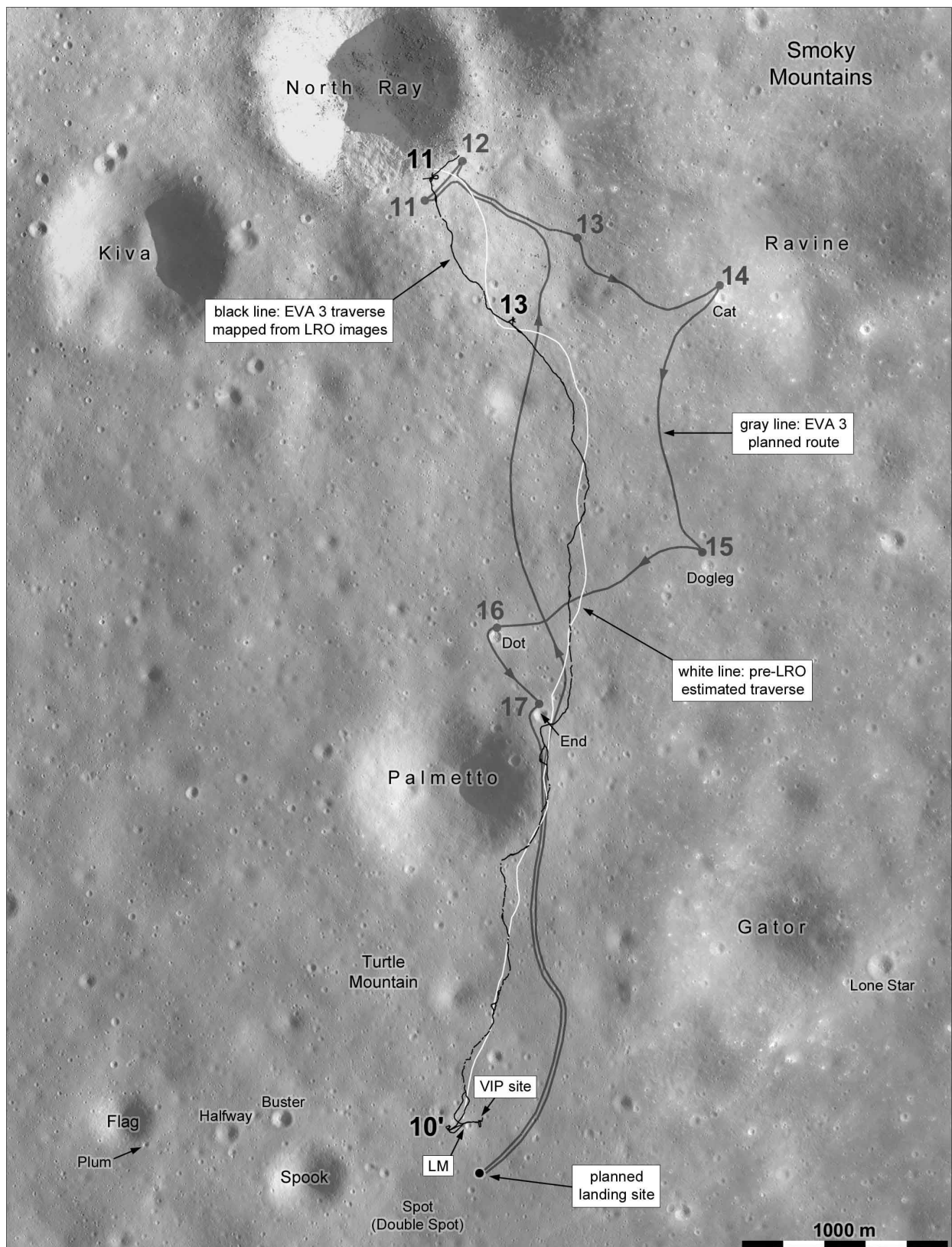


Figure 275. Apollo 16 EVA 3, context map.

Young pointed out that the bottom was not in view from here and said "Maybe we can drive around to the other side and see down into it". The crater rim was tilted down to the north because it formed on the edge of a hill, but they were not given the opportunity to view it from the other direction. Duke walked over to join Young and then used the 500 mm telephoto lens to take pictures of the crater interior as Young described the scene and began sampling. Many images were again blurred as Duke held the camera unsteadily. Then Duke climbed back up the slope towards the rover to get a better view of Smoky Mountains and used the telephoto lens to image the massif. He left the lens on the rover.

Another set of images would be taken with polarizing filters to study the nature of reflected light and what it might reveal about the rocks. A 'near field' experiment would photograph rocks from different directions, but it was dropped to save time. The 'far field' experiment would photograph the far wall of the crater with three different filters from two separate stations. Duke took the first set of three half panoramas of the far wall using the polarizing filters from a position about 20 m northwest of the rover while Young was preparing to collect samples along the crater rim to the northeast. He dropped his sample bags without noticing and walked on, then had to retrace his steps until he found them. He picked them up, falling over in the process.

Duke returned to the rover for the telephoto lens and then ran out to join Young, who collected samples while Duke took the second set of polarization half-panoramas. The locations of photography stations including the LRV TV panorama in Figure 281 are based on reprojected near-field versions of these panoramas and are better defined than maps in the contemporary documents. Duke now switched lenses to finish a film with the 500 mm lens, photographing the far wall of the crater. Young dropped his sample bags again but retrieved them without trouble, and now Duke found that he had dropped his bags. Young dug a shallow trench and Duke discarded the polarization filter which was no longer needed.

Both astronauts continued sampling and Duke noted that he could look south and see South Ray, Baby Ray and the mountain Kenesaw beyond Stone Mountain. They returned to the rover and then sampled the large white boulders west of it, working together to sample and hold bags as they were continuing to have trouble holding onto them. They used the rake as a scoop to sample part of the fillet surrounding one of the rocks, and they were asked to look for a rock which might have a patch of permanent shadow on its southern side. They did not find one here. They continued sampling rocks and soil, took a rake sample near one of the rocks and then a second rake sample near the rover.

England announced that they would be given some extra time here, so the astronauts stowed their samples on the rover and ran out to House Rock. They stopped half way to the rock for a rake sample and a separate soil sample, finding a white layer under the top centimetre of gray regolith. Running on to maximize their time at the rock, they stopped near a detached portion of the rock jokingly called Outhouse Rock. Young was interested in finding a permanently shadowed area at the base of the rock but they decided that nowhere was suitable. They inspected and photographed the huge rock including a shatter cone, a structure produced by impact shock, and collected samples from the rock.

After a final soil sample was collected and bagged, they ran back to the rover and began stowing their samples and tools in preparation for the trip to the next station. Duke noted that the surface here consisted of rocks under a thin layer of fine regolith, and it was often hard to dig in with the rake or scoop to collect soil. He changed the film magazine in the 16 mm camera as Young worked with the sample bags. Finally they turned off the TV and drove away, turning in a tight clockwise loop and crossing their northbound tracks to depart slightly west of them. Very soon they rejoined the tracks and followed them back to the southeast.

The drive down off the rim of North Ray was steep, and Young claimed a lunar speed record of 17 km/hour but England asked him not to set any more. They levelled out as they crossed North Ray Ridge and then sped down the next slope off the ridge, arriving in only a few minutes at the group of large rocks where Station 13 would be located. They passed a rock with a pronounced fillet of regolith around it, turned sharply and stopped beside another rock with no fillet which would be their Station 13 (Figures 279, 281). Duke took a panorama and Young started the TV. Then they began sampling, first with Duke using the rake to collect small fragments. The surface was easier to rake here but there were not many small rocks.

The TV showed the shadow at the southern foot of Shadow Rock (a name which was only used after the mission, not here at the site itself). England suggested they scoop some shaded material even though there was not enough time for a proper sampling of potentially permanently shaded regolith, and they had lost the vacuum container which would have been needed for a pristine sample. It had fallen off the rover early in the EVA. Young set out the magnetometer east of the rover while Duke chipped fragments off Shadow rock. He said he thought that some regolith close to the base of the rock really was in permanent shadow. He collected and bagged some of it and was asked to collect a second deeper sample at the same place.

Duke finished sampling and photographing Shadow Rock, falling against the rock in the process, as Young took his magnetometer reading and then stowed the instrument back on the rover. They climbed onto the rover and set off back to the LM, driving along their outbound tracks as Duke took photographs to document the route. They had a good view of the distinctly raised rim of Palmetto with End on its northeastern edge and Dot further west. Large blocks were visible on the north side of Palmetto. As they drove away from North Ray they encountered a smooth area which seemed to lie between the two blocky ejecta blankets of North Ray and South Ray.

Young asked if Duke would like to take pictures of the interior of Palmetto and he assented, suggesting they climb the rim near Dot, though Young stayed on their tracks instead. Young suggested they take a 360° rover panorama as they had done late in EVA 2, telling England they had 'developed a new technique for panning... 360° on the rover'. The astronauts thought they were crossing a patch of ejecta from South Ray when they encountered numerous scattered rocks. As they drove on England told them the magnetometer data from Station 13 showed the strongest field yet measured on the Moon, and he advised them to turn off the 16 mm camera to save LRV battery power. Duke wondered if small fresh craters with glassy melt could be dated from samples, thinking he might collect some on the rim of Palmetto, and England checked with the geologists who thought it might be possible, but they did not have time to stop.

The crew described their view of the rocky rim of End crater, and also the spray of regolith from the rear wheel whose fender had been damaged, which made them and the rover very dirty. Duke said 'Don't anybody tell Ken [Mattingly] how dirty we are' and Young suggested Mattingly wouldn't let them back into the CSM. After their long descent from North Ray Ridge and the surrounding terrain, they found themselves climbing again, passing End and approaching the rim of Palmetto. England said their drive was picked up in both directions by the seismometer and geophones and asked them to confirm they were closely following their tracks.

Duke noted the view into Palmetto on their right and asked Young to turn right and let him take a rover panorama (Figures 277, 285). Young drove off their outbound tracks to get closer to the rim and looped round in a tight counterclockwise circle. Duke took pictures as they faced north, west and south, making a half-panorama which showed the shadow-free crater walls.

As they returned to the outbound tracks to follow them home, Young suggested that Palmetto's rim would have been a good target for a walking traverse if the rover had failed. They described rocks as they passed them, including one large enough to scrape the bottom of the rover which appeared suddenly and was narrowly avoided. The LM was not yet visible but their tracks were easy to follow. England reported from Houston that Mattingly had now performed a manoeuvre to change the CSM orbit plane to fly over the landing site when the LM departed. Young asked England about the magnetometer readings they had taken, which were much higher than those seen at Apollo 14.

As they descended from the raised rim of Palmetto Duke pointed out a crater which lacked a raised rim, likening it to 'doodlebug' holes he had seen as a child, holes in dry sandy soil dug by insect larvae. He was seeing again the depression 600 m north of the LM which he had earlier called a 'big sag'. Steering sharply around several craters caused them to lose traction and spin briefly, but they recovered and Duke asked for a chance to photograph the interior of the 'doodlebug' crater. They did not attempt a full rover panorama here but diverted towards the crater briefly and then turned back onto their tracks, giving Duke enough time to take three frames showing the crater interior. Young also took a few images during this part of the drive, steering with one hand as he did so.

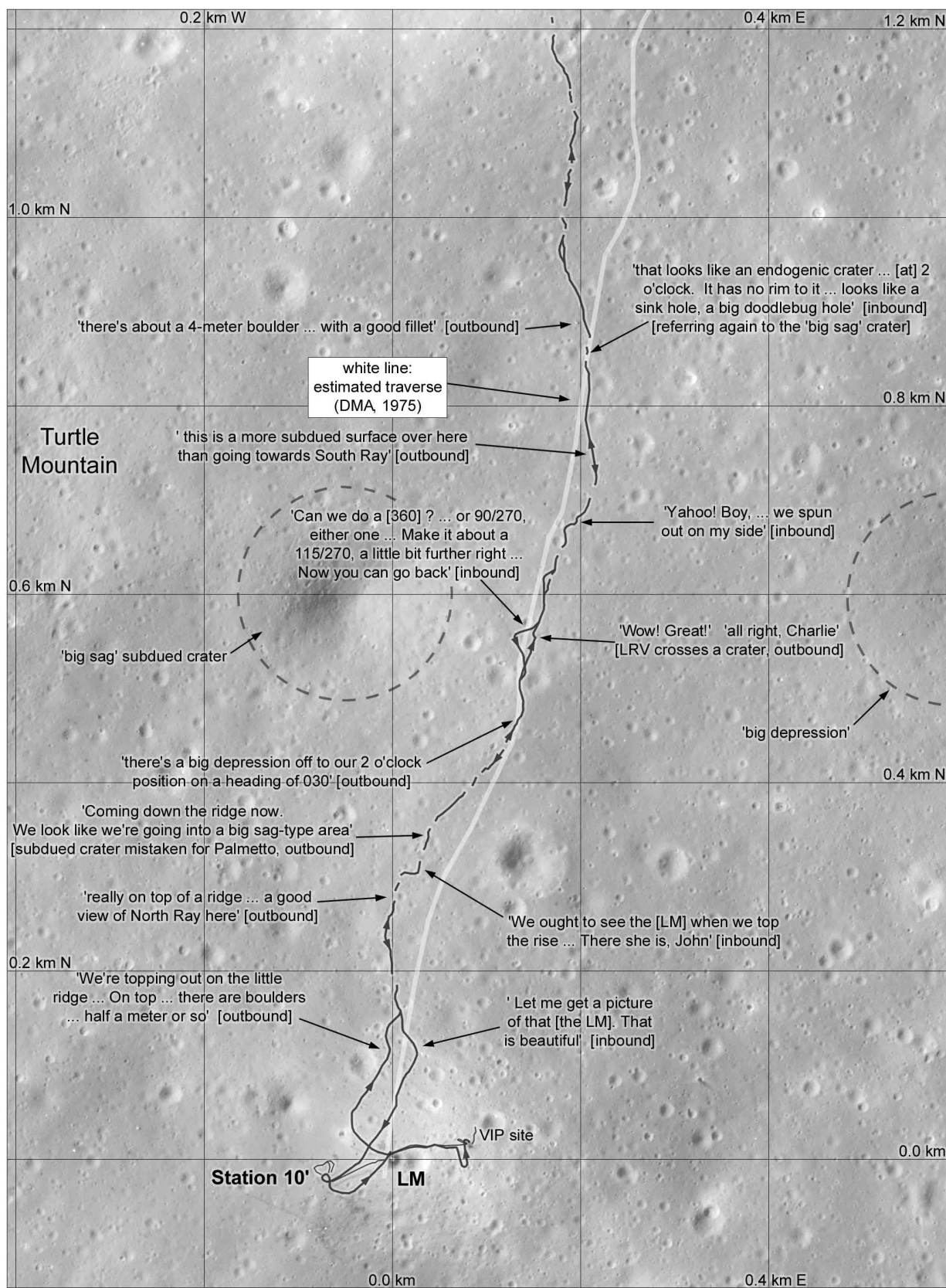


Figure 276. Apollo 16 EVA 3, map 1.

Soon they topped a low ridge and saw the LM about 300 m away. Young turned the rover slightly so his view of the LM was not blocked by the antenna mast and took two more pictures. Now they could plan their approach. England asked them to pick a spot on the edge of a ray for Station 10', about 50 m north of the ALSEP. The geologists on Earth wanted samples of rocks the crew had described earlier as vesicular basalts. Duke noticed the 16 mm camera had stopped running, probably because its battery was depleted, but both astronauts photographed the LM as they approached. They found an area suitable for Station 10', though ray boundaries were too gradational to be sure they were on one, and Young parked facing southwards.

Young pointed the rover antenna at Earth, guided by Duke, but then dropped the brush they used to clean rover surfaces, and as he picked it up he knocked the antenna and had to point it again. Duke took a panorama nearby and was then directed to collect a rake sample and a double core. Young helped him put the rake sample in a sample bag and photographed the two rake swaths. They walked over to the Station 10 site and collected another rake sample near the previous double core location. There were fewer rock fragments in the regolith here so Young took four swaths, bagged the rake sample and then collected a separate regolith sample nearby. Duke broke a fragment off a rock with his hammer, finding it was glassy rather than the vesicular rock he expected. He spotted another of the glass balls and they collected it.

The scientists in Houston wanted to check that the mortar package was set up properly, but if they sent both astronauts to look at it there would not be time to take a double core at Station 10'. As they were thinking about sending Young to check it the TV camera zoomed in to view it. It seemed to be satisfactory. Duke prepared the double core tube at the LRV using the handle from the rake, which they no longer needed. He threw it away and pushed the core tube into the ground, then hammered it in as far as he could before it hit an obstacle, as Young collected rock samples nearby. Duke helped collect rocks and then ran back to the LM to see if he could see any of the supposedly vesicular rocks. He examined several samples before collecting a black rock, at the same time that Young was picking up a white rock back at the rover. He drove it back to the LM and parked north of the ladder, pointing the antenna again for the TV camera, though this proved difficult even with Duke helping him.

Duke collected a few last samples while Young brushed dust off the rover to reduce heating and then pointed the UV telescope to its final target. They began stowing samples and discarding their tool harnesses, and Duke deposited a medallion commemorating the 25th anniversary of the founding of the US Air Force. He also set out a photograph of his family and a piece of cloth on which he had written 64-C, referring to his test pilot school class. Stuart Roosa (the Apollo 14 Command Module Pilot) had been in test pilot school with Duke and was now at Mission Control in Houston. Duke told him, via England, that Apollo 16's lunar work had surpassed their class climb of Mt. Whitney in California in 1964. Young tried to free the data plate from the cosmic ray detector mounted on the side of the LM, but had trouble detaching it by hand. It had been in sunlight and felt hot even through his gloves. Duke assisted, and by using pliers Young was able to free it. A temperature label, which became darker as it heated up, showed its temperature as 180 °F (82 °C).

The schedule included time for a 'grand prix' driving test if they had not been able to do it earlier, but it was no longer needed. Duke collected the SWP which had been standing near the LM since EVA 1 and wound it up for return to Earth. He threw the SWC staff away like a javelin, like many other Apollo astronauts who enjoyed the experience of throwing things in lunar gravity and seeing how far they would fly. They continued collecting the rock samples, core tubes, film magazines and other items which needed to be brought home, describing them so people on Earth could keep track and ensure nothing was left. The items were placed in Equipment Transfer Bags to carry them up to the LM cabin.

The astronauts had unofficially planned a brief interlude where they would do a long jump and a high jump, calling it the Descartes Olympics in honour of the Munich Olympics which would be held later that year. Just before Young drove the rover out to the VIP launch viewing site 80 m east of the LM he steadied himself by holding onto it and made several jumps, then two without holding on. Duke also jumped but his heavy backpack pulled him over backwards and he landed heavily, luckily not damaging anything. He was now so dirty that he would need to be brushed off before entering the cabin, though in fact both astronauts had been very dirty already. Chastened, he began bringing materials up to the LM porch as Young drove the LRV out to its final parking spot, the VIP site (Figures 276, 281).

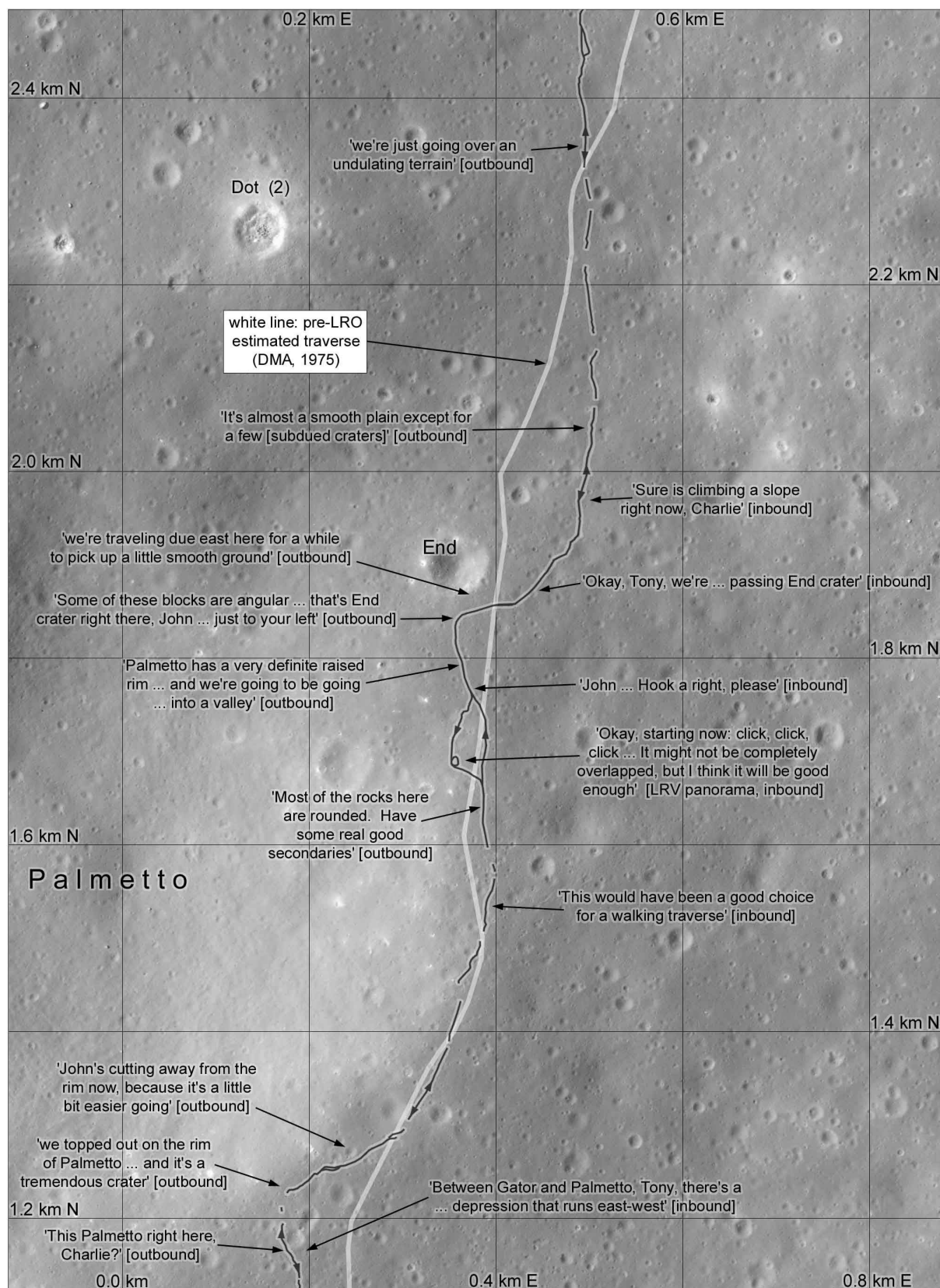


Figure 277. Apollo 16 EVA 3, map2.

Young had chosen a VIP location east of the 25 m diameter crater he had flown over just before landing, as the pre-planned location was in the crater. He drove north of the crater, turned south to be directly east of the LM and then north again to find an ideal location (Figures 276, 281), finally parking facing slightly east of south. The total distance driven was 26.7 km. He read out instrument values to the ground and dusted parts of the rover to help keep it cool enough to function until they had departed.

By now Duke had taken two bags of samples and equipment up to the LM porch, and checked that discarded items were pushed under the LM so they would not blow out over the ALSEP during launch as almost happened on Apollo 15. Young pointed the rover antenna at the crescent Earth to allow TV transmissions, finding it difficult as he had done earlier. Duke was asked to go to the VIP site and look for a rock to place on the magnetometer. He ran out and found a rock, thought it was too large to bring back and looked for a more suitable candidate, finding one he said was half the size of an orange. He put it on the rover seat, dusted the rover more, and pulled a thermal blanket free and placed it over the electronics box to help keep it cool.

Young set up the magnetometer about 10 m west of the rover and came back to the rover to take the instrument reading. Duke finished the last dusting of the rover, which Houston was eager to keep from overheating so they could view the LM liftoff. Then he headed back to the LM and Young put the selected rock on top of the Magnetometer, photographed it, returned to the rover and took the new measurement. Then he put the rock in a bag and brought it back to the LM. The astronauts dusted each other as thoroughly as they could, from helmet to boots, and Duke pointed out a rock under the LM which had not been moved by the rocket exhaust plume during landing.

Duke climbed the ladder and entered the LM, and Young collected the film magazine from the UV telescope. He hooked the last transfer bag to a lanyard, climbed the ladder and pulled the bag up. Then he returned to the surface for the last bag containing several large rocks, brought it up and entered the LM. The hatch was closed and the cabin repressurized to end the 5.7 hour EVA. The total time for all three EVAs was 20.25 hours. The crew worked on preparing the PLSS units for removal and noted poor communications at the moment because the LM high gain antenna could not be pointed properly. They weighed the sample bags to keep track of liftoff mass, which was going to be higher than intended, and the team in Houston considered whether to jettison some samples but decided that was not necessary.

The astronauts put their gloves back on and checked the pressure integrity of their suits before the last depressurization. Young had trouble getting a good seal in one of his gloves as the seals were so dirty, so they considered removing their helmets to blow dust off the glove seals, risking difficulty with the helmet seals as well. The glove was eventually sealed well enough for the crew to open the hatch and push out the PLSS backpacks. Then they repressurized and removed their helmets and gloves for the last time. The helmets were hard to remove because leaking orange juice from the in-suit drinking system had seeped into the seal and dried.

The dirty sample bags were covered with clean Sample Containment Bags to help reduce loose dust in the cabin during weightlessness. Apollo 15's Jim Irwin now took over the CapCom post for the return to orbit, and helped guide the stowage of samples to balance the LM for liftoff. Communications improved now as the large antenna at Goldstone, near Los Angeles, took over from a smaller antenna in Spain. The crew prepared for liftoff, tested communications with Mattingly in the orbiting CSM as it passed overhead and took time for a brief meal. Numerous changes to plans and timelines were read up to them in preparation for the return to orbit.

The rendezvous radar was moved into position and Duke set up the 16 mm camera in his window to monitor the liftoff and ascent. The LM power and supplies were ample and Irwin jokingly asked if they would like a fourth EVA. Duke said he would if he could have a sleep. The LM lifted off at 01:26 UT on 24 April and the LRV TV camera captured the launch. It followed the spacecraft until it became too faint to see, occasionally losing track of it early in the flight, and then returned to view the LM descent stage.

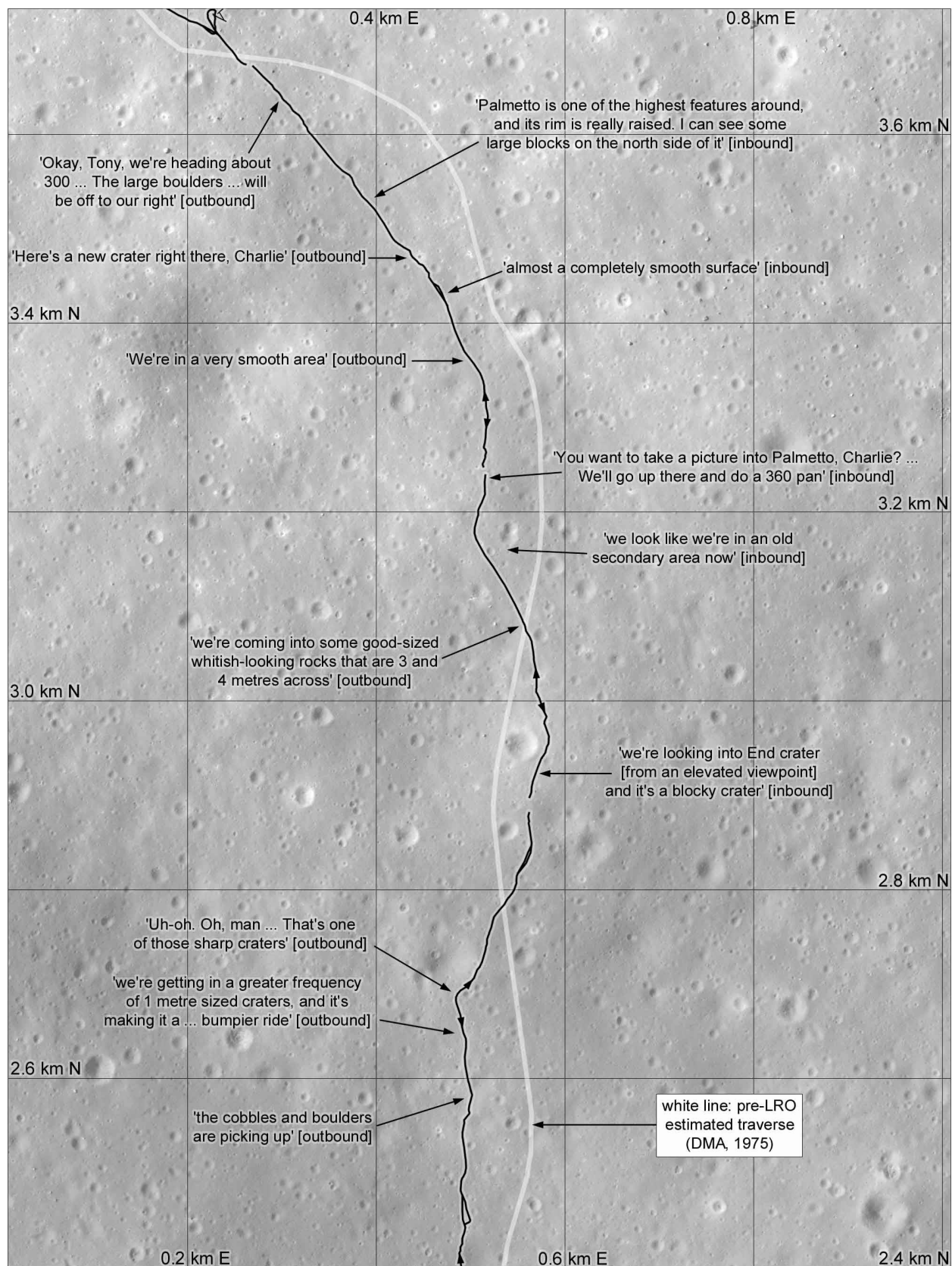


Figure 278. Apollo 16 EVA 3, map 3.

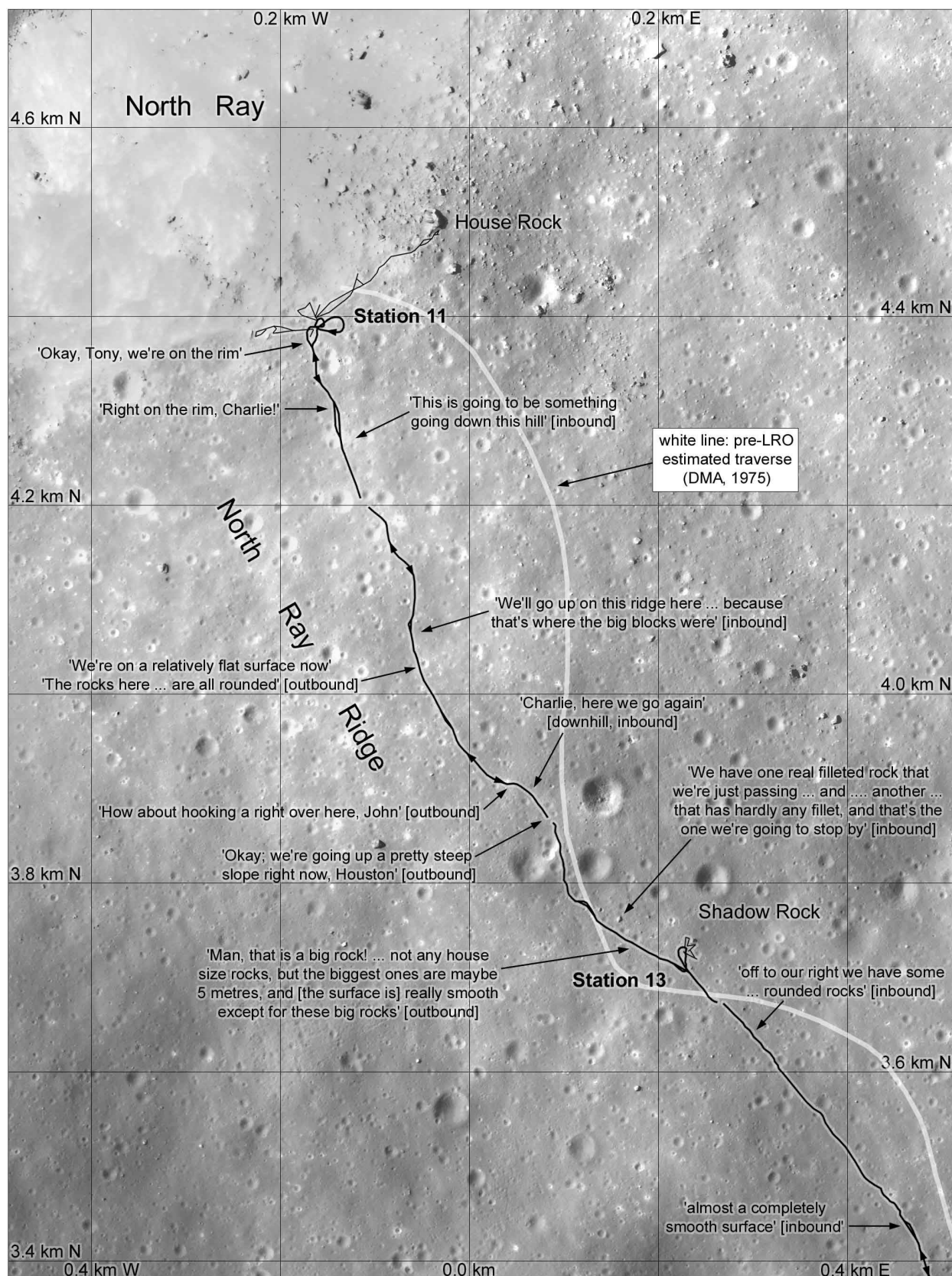


Figure 279. Apollo 16 EVA 3, map 4.

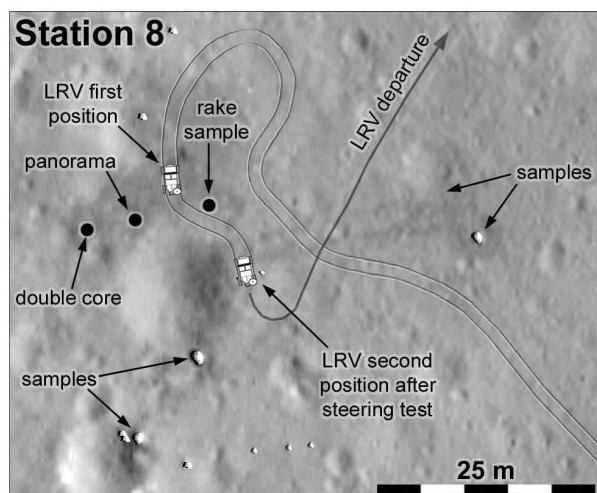
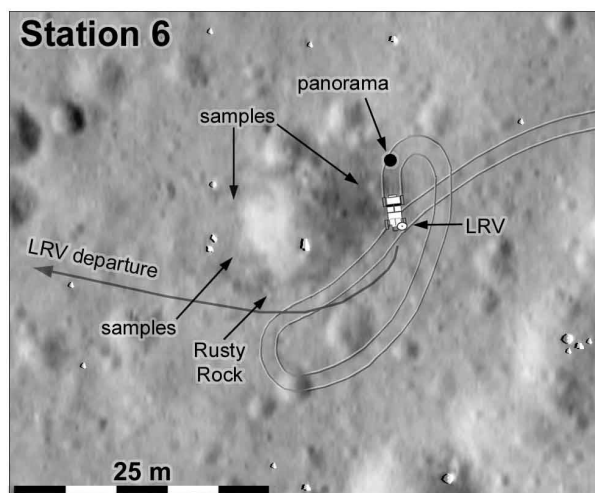
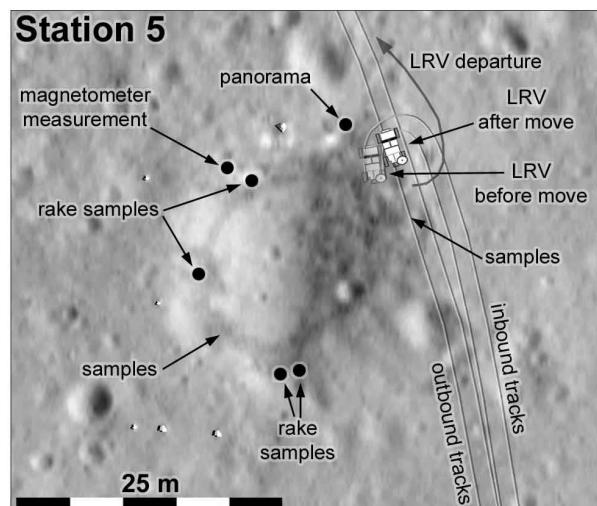
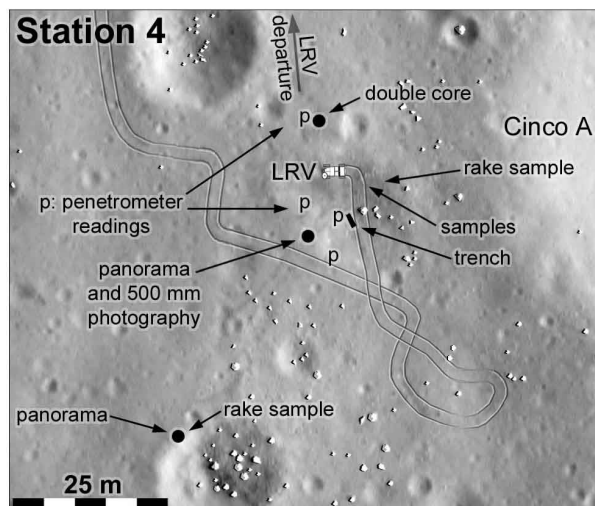
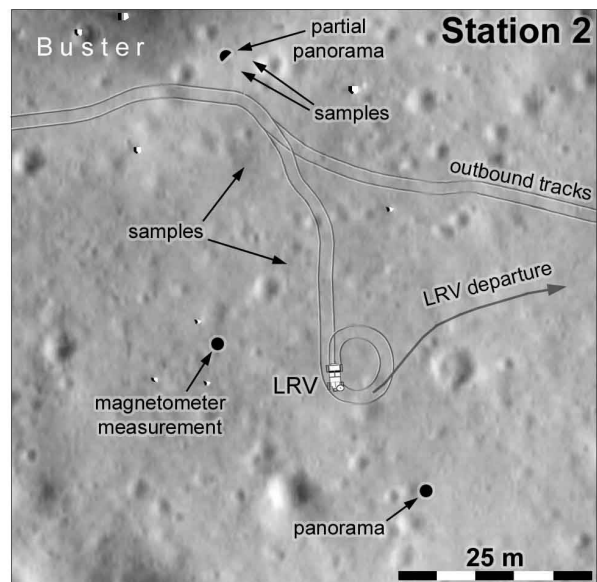
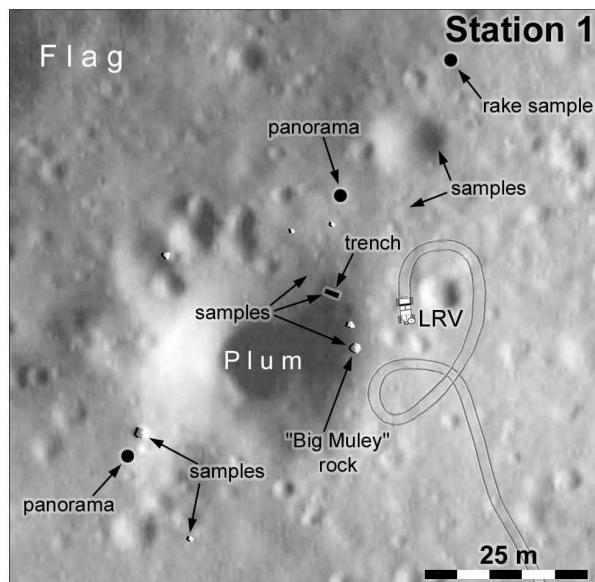


Figure 280. Apollo 16 traverse stations 1-8. LRV tracks are illustrated as they were during station activities.

After the LM was unloaded and sealed it was jettisoned. The plan had been to perform a deorbit burn to cause an impact near the landing site (Figure 264A) and create a seismic signal. The LM lost attitude control as it was jettisoned, possibly because it was incorrectly configured before it was sealed, and no further commands could be carried out. The LM was assumed to have struck the lunar surface during the next few months at an undetermined location within 10° of the equator. The impact site was located eventually by James Meador (Figures 287, 288). Shortly after the LM jettison, the Service Module's Mass Spectrometer boom was also jettisoned because it could not be properly retracted. This also would have fallen to the surface eventually.

The subsatellite was ejected while the CSM was over the far side. It transmitted on the same frequency as the LM and experienced some interference because of that. As the LM could not be deorbited the subsatellite was not commanded until the LM batteries depleted about 9 days later.

The mortar for the Active Seismic Experiment was to fire four grenades to distances of 1500 m, 900 m, 300 m and 150 m to provide signals for the seismometer. Comparison with Figure 268A shows the most distant grenade would have landed about 300 m north of Flag crater. Three grenades were fired on 23 May but the most distant was not because mortar orientation data became uncertain and the firing might damage other ALSEP equipment. The other three gave good seismic data, probing the subsurface to reveal layers of different material beneath the site. Figure 268 shows the intended grenade impact locations. Several small dark spots are observed along that line in high sun images but only one is near a predicted impact location and might be a grenade impact site (Figure 269). Lower sun images show it to be a small crater.

The Apollo 16 samples were originally expected to include highland volcanic materials, but instead consisted of basin ejecta. There has been some uncertainty about the source of this material, particularly whether it consists of Nectaris ejecta as originally assumed (Head, 1974), or Imbrium ejecta (e.g. Norman *et al.*, 2010).

The Apollo 16 science stations are mapped in Figures 280 and 281. These plans are modified from sketches in the Muehlberger *et al.*, 1972, incorporating additional details from orbital images and surface panoramas and plotted on LROC images. The Station 5 location is different from that suggested by Sanchez (1981) and the Apollo Lunar Surface Journal (since corrected). Stations 10 and 10' are shown in Figure 266A. Stations 3 and 7 were not visited, and Station 11 here includes Station 12 as originally planned (Figure 275).

Selected Apollo 16 panoramas are shown in Figure 282. In Figures 283 and 284 several of these panoramas are presented in a circular format to show azimuths to horizon features. The heights of horizon features are exaggerated in these projections. All four rover panoramas are shown in Figure 285.

Apollo 16 orbital photographic coverage is mapped in Figure 286. A small area northwest of Grimaldi was photographed in earthshine. High resolution coverage runs south of the Apollo 15 image area (Figure 250), greatly increasing the area seen at very high resolution. A wider region was observed at lower resolution as Apollo 16 departed from the Moon.

After the return to orbit, the spent LM Ascent Stage (LMAS) was intended to be crashed at 9° 29' S, 14° 58' E (the Apollo 16 Final Flight Plan gives 9.50° S, 14.98° E), about 25 km southwest of the landing site (Figure 264A), to provide a seismic signal as on Apollos 12, 14 and 15. The LRV TV camera was to be aimed at the appropriate azimuth at full zoom in the hope of observing a plume of ejecta rising over the horizon. Control of the LMAS was lost after it was jettisoned and it was abandoned in lunar orbit. It was long assumed to have crashed at some time during the next year or two, at an unknown location within 10° of the equator, but an analysis in 2021 suggested it struck the surface on the eastern rim of the large crater Neper on 31 May or 1 June 1972 (Meador, J., personal communication, 20 July 2021). This was revised in 2022 to a location around 104° E (Figures 287, 288) on 29 May 1972.

The probable impact site of the LMAS was found (Figure 288) using Meador's predictions (Meador, 2022a, b) in LROC NAC images (Meador and Stooke, 2023). The site was not imaged at high resolution prior to the impact for comparison and was in shadow in the only Apollo 16 panoramic camera image of the site (Figure 288).

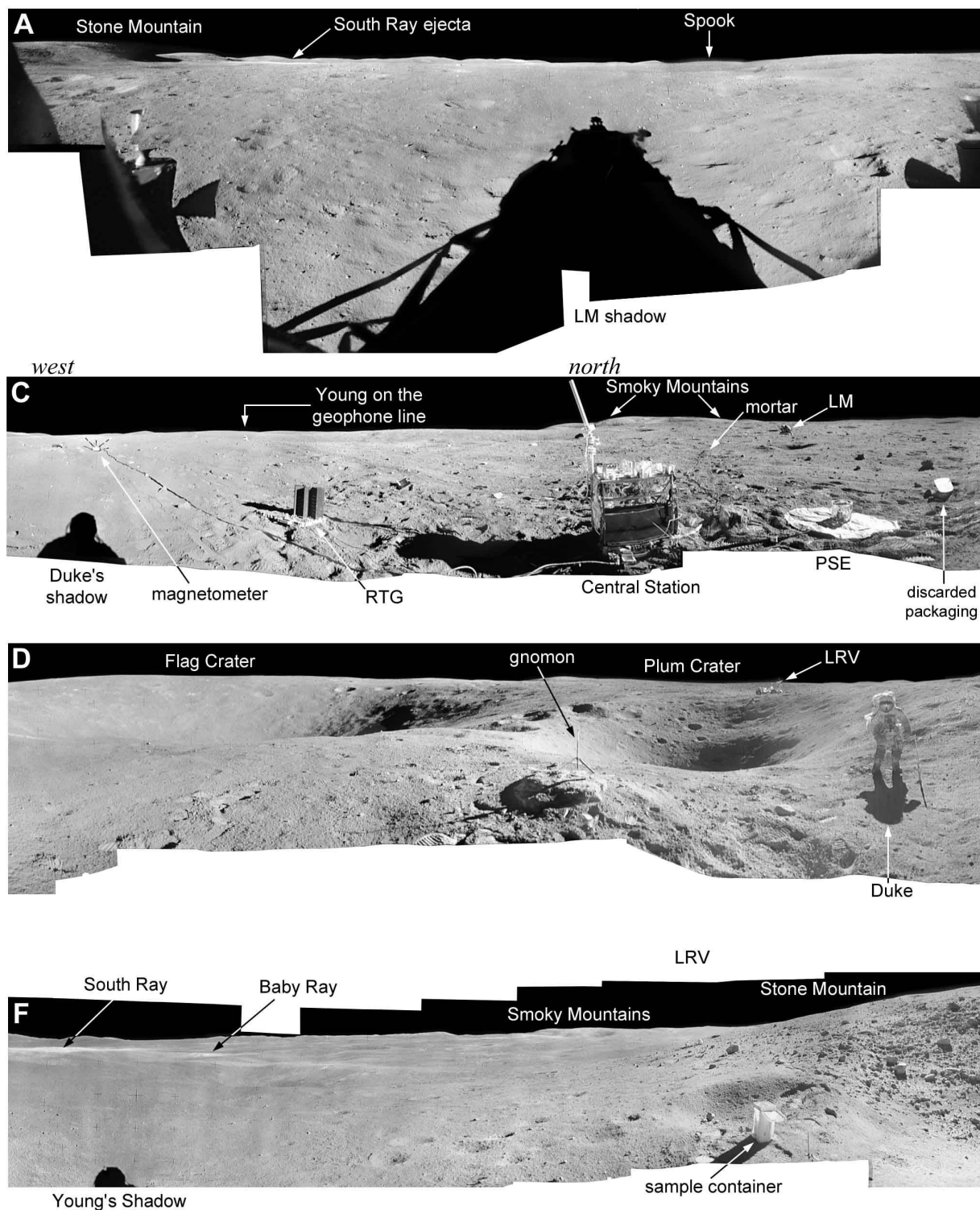
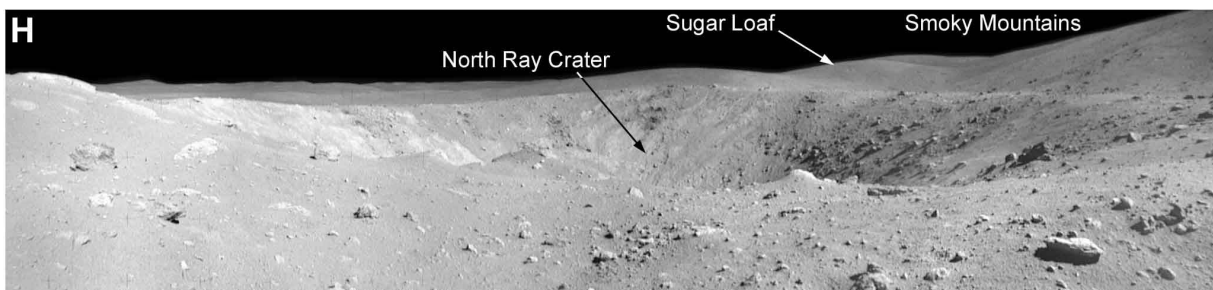
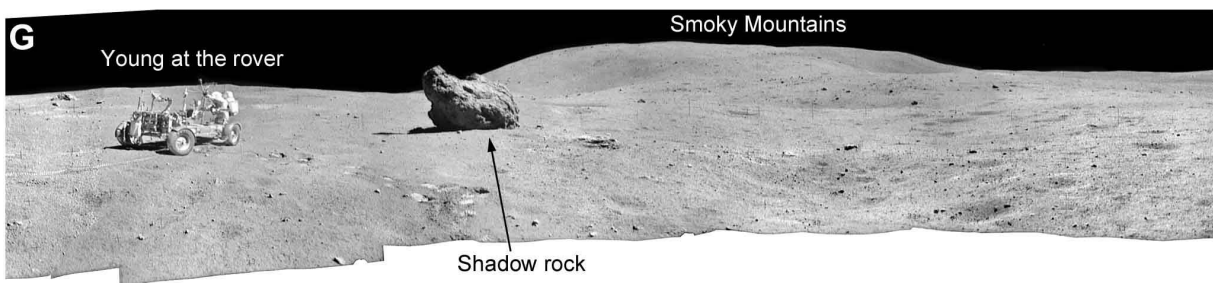
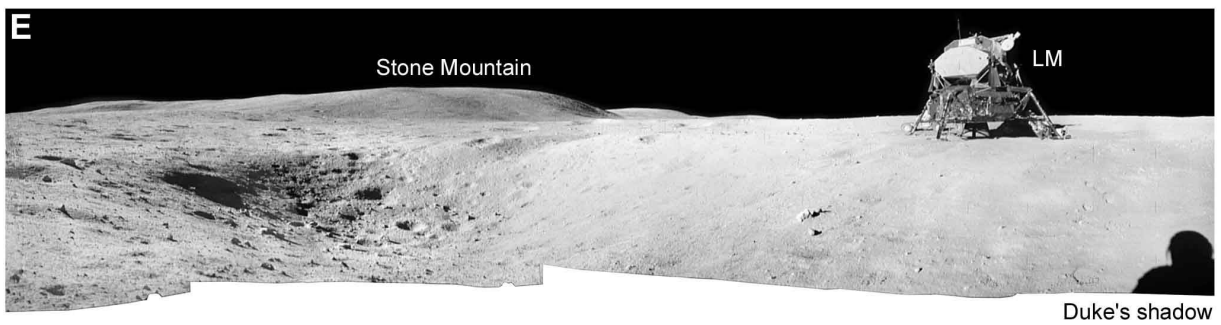
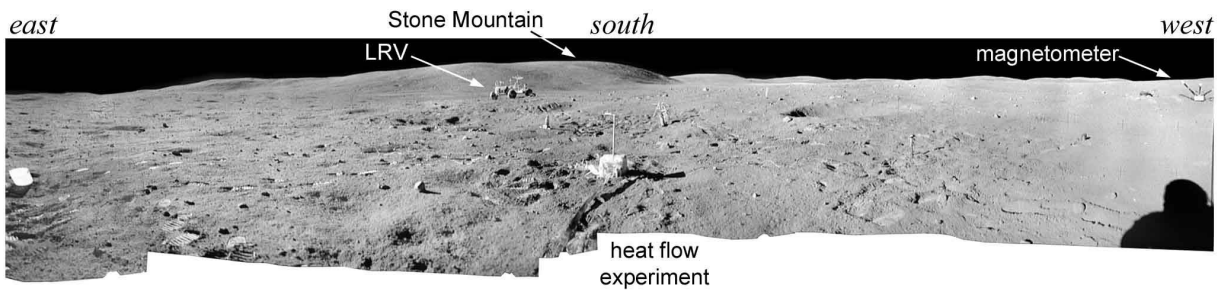
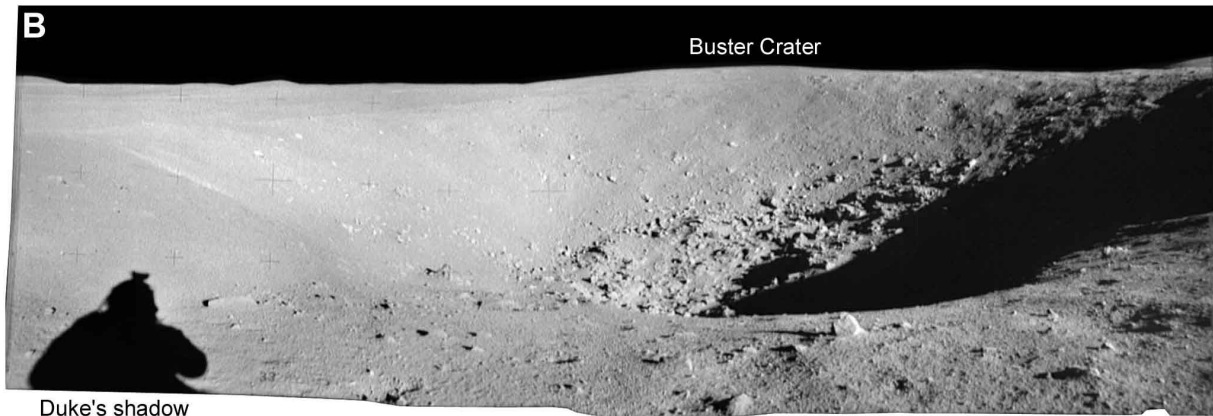


Figure 282 (both pages): Apollo 16 panoramas. A: view to the west from the LM windows just after landing, the only Apollo 16 window panorama. B: Buster crater from Station 2, looking north. C (across both pages): ALSEP panorama taken during EVA 1. D: looking north and east from Station 1. E: view south and west from near the LM. F: looks west and north from Station 4. G: Shadow Rock at Station 13. H: one of the Station 11 polarization panoramas looking northwest across North Ray crater. All panoramas were assembled by P. Stooke.



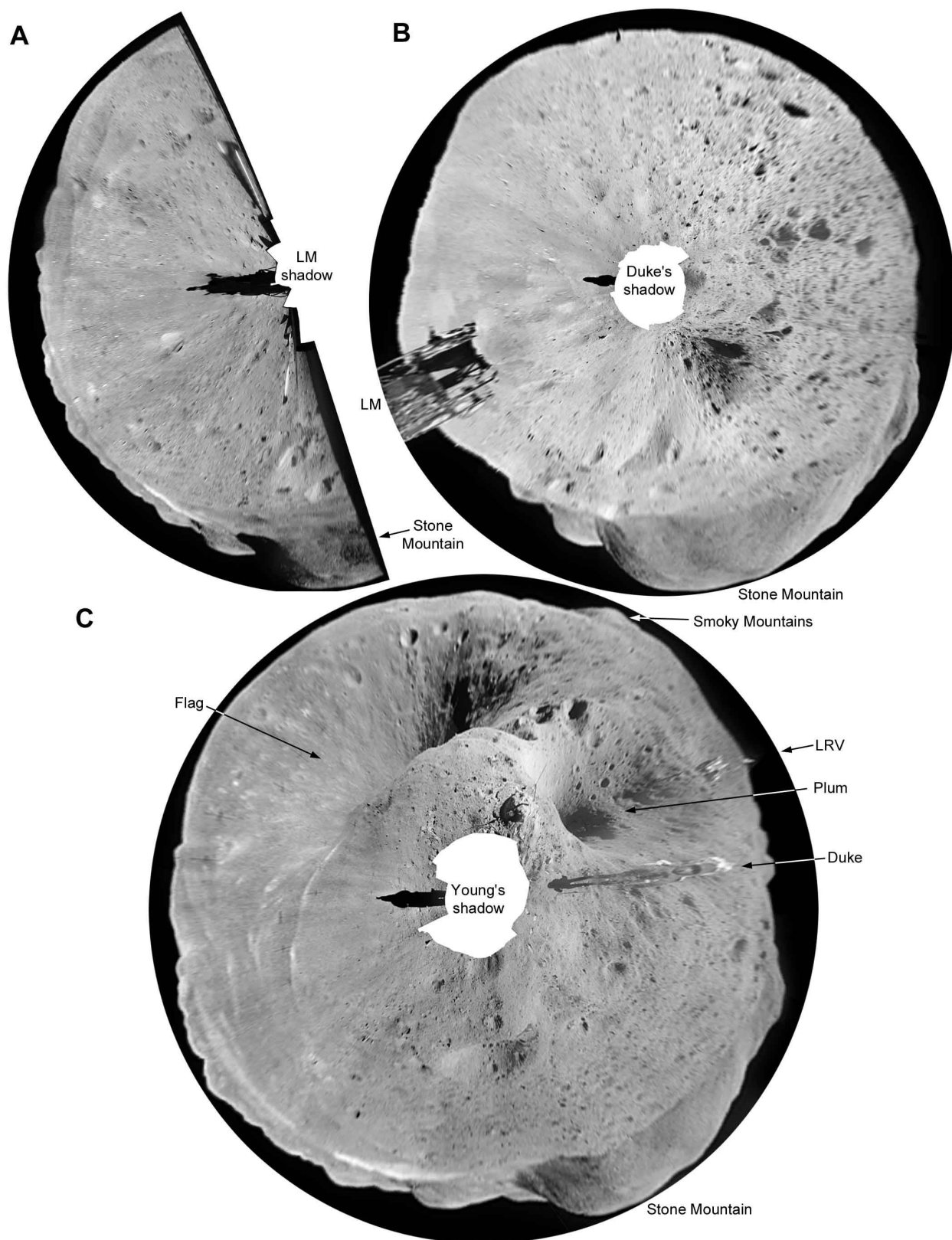


Figure 283. Apollo 16 panoramas in circular format. Horizon feature heights are exaggerated. A: view from the LM window before EVA 1. B: panorama northeast of the LM. C: panorama at Station 1.

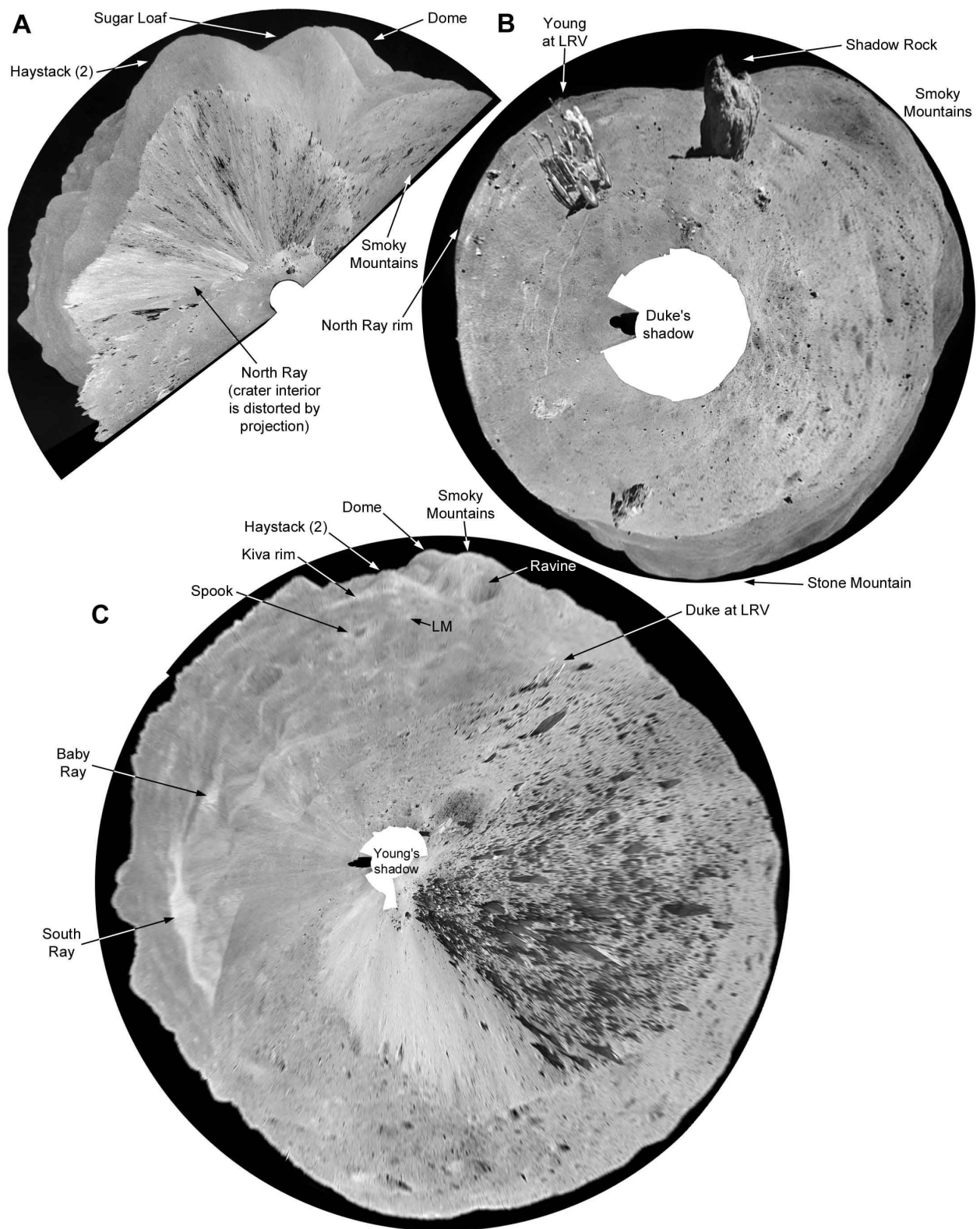


Figure 284. Apollo 16 panoramas in circular format. Horizon feature heights are exaggerated. A: North Ray crater, EVA 3. B: Station 13 at Shadow Rock. C: Station 4 on Stone Mountain.

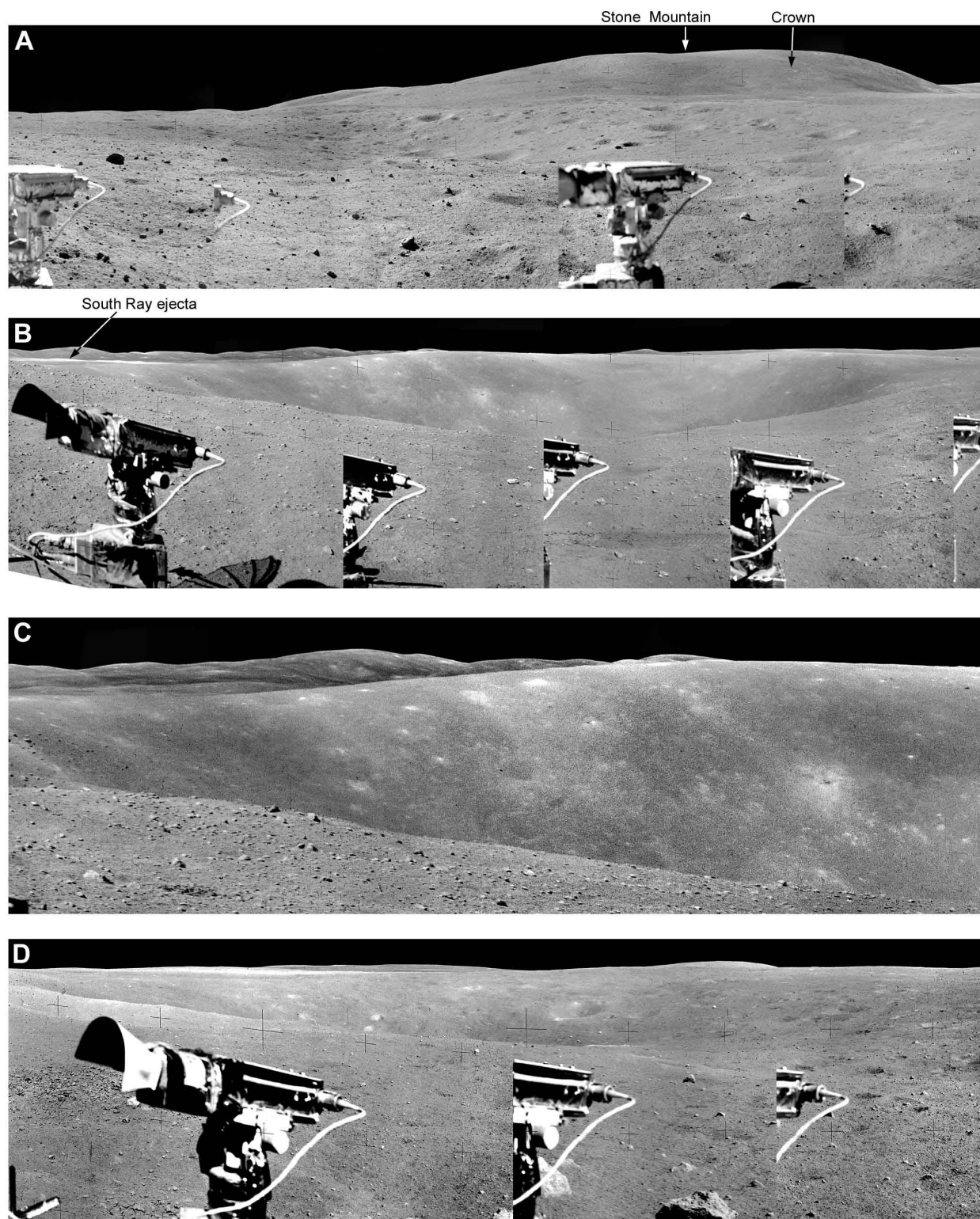


Figure 285. Rover panoramas. A: looking south over the subdued crater on EVA 2. B: looking west over Palmetto, EVA 3. C: enlarged view of the interior of Palmetto. D: looking west over the 'big sag' or 'doodlebug hole' on EVA 3.

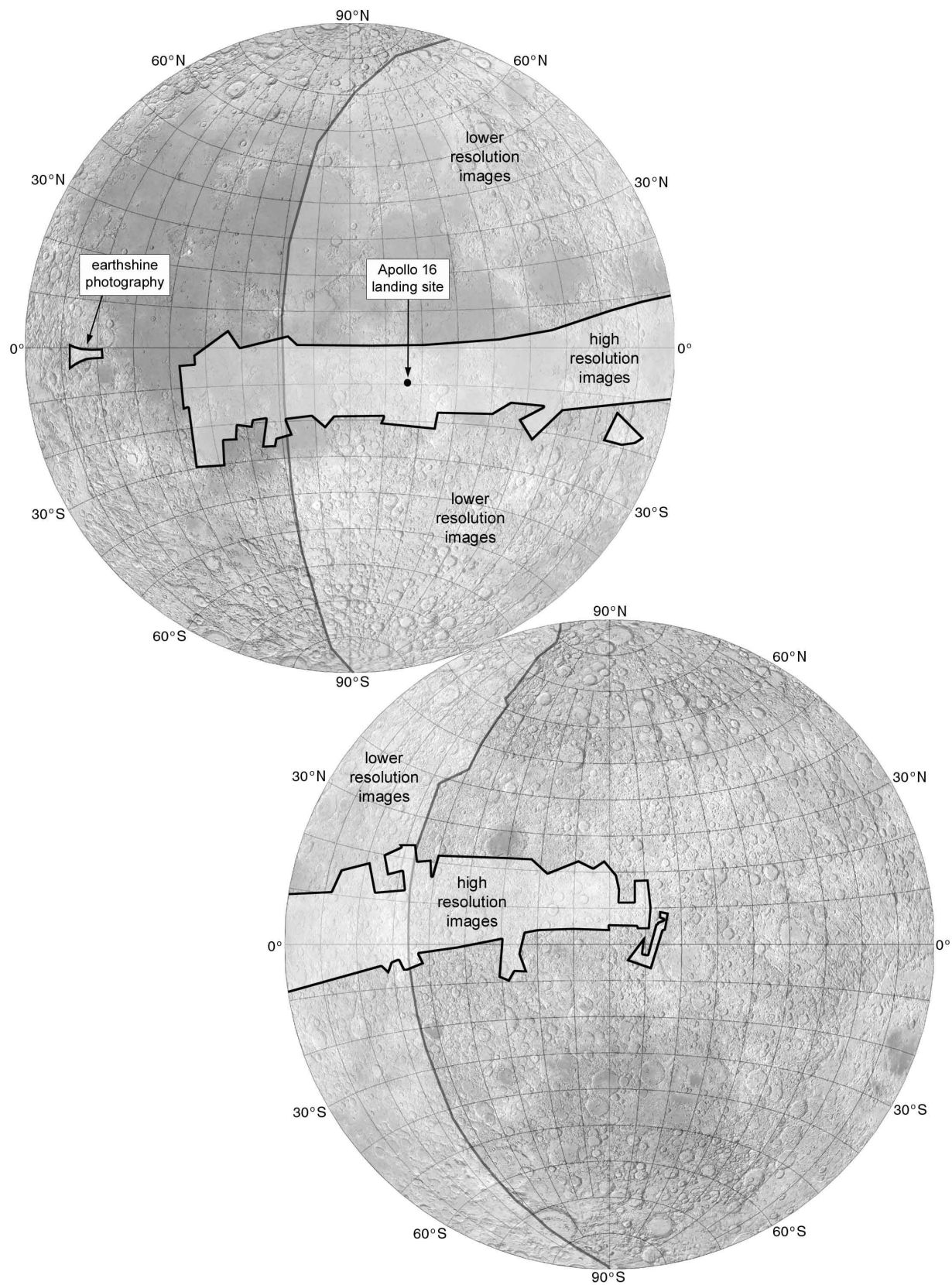


Figure 286. Apollo 16 orbital photographic coverage.

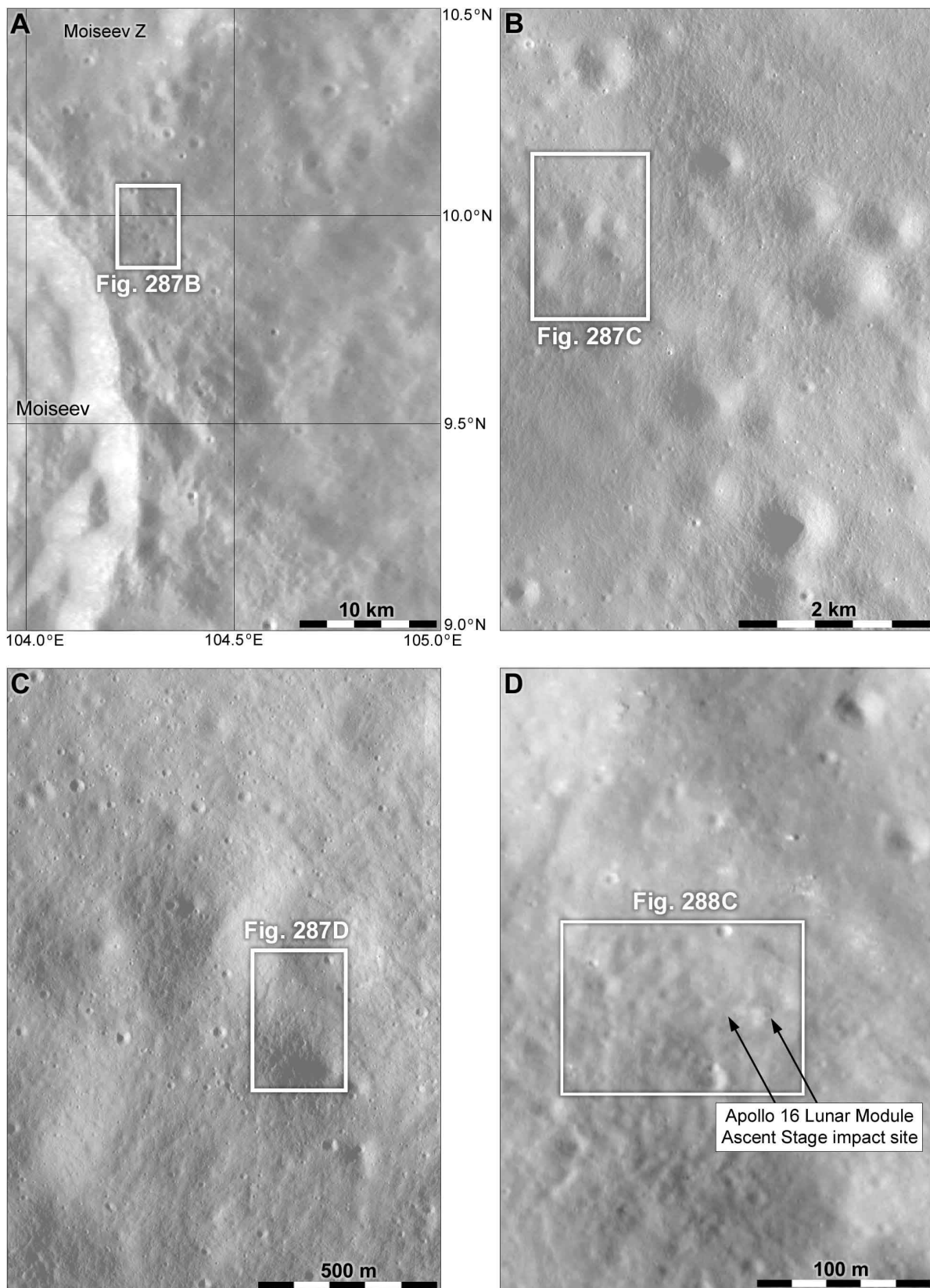


Figure 287. Apollo 16 Lunar Module Ascent Stage impact site from Meador and Stooke (2023).

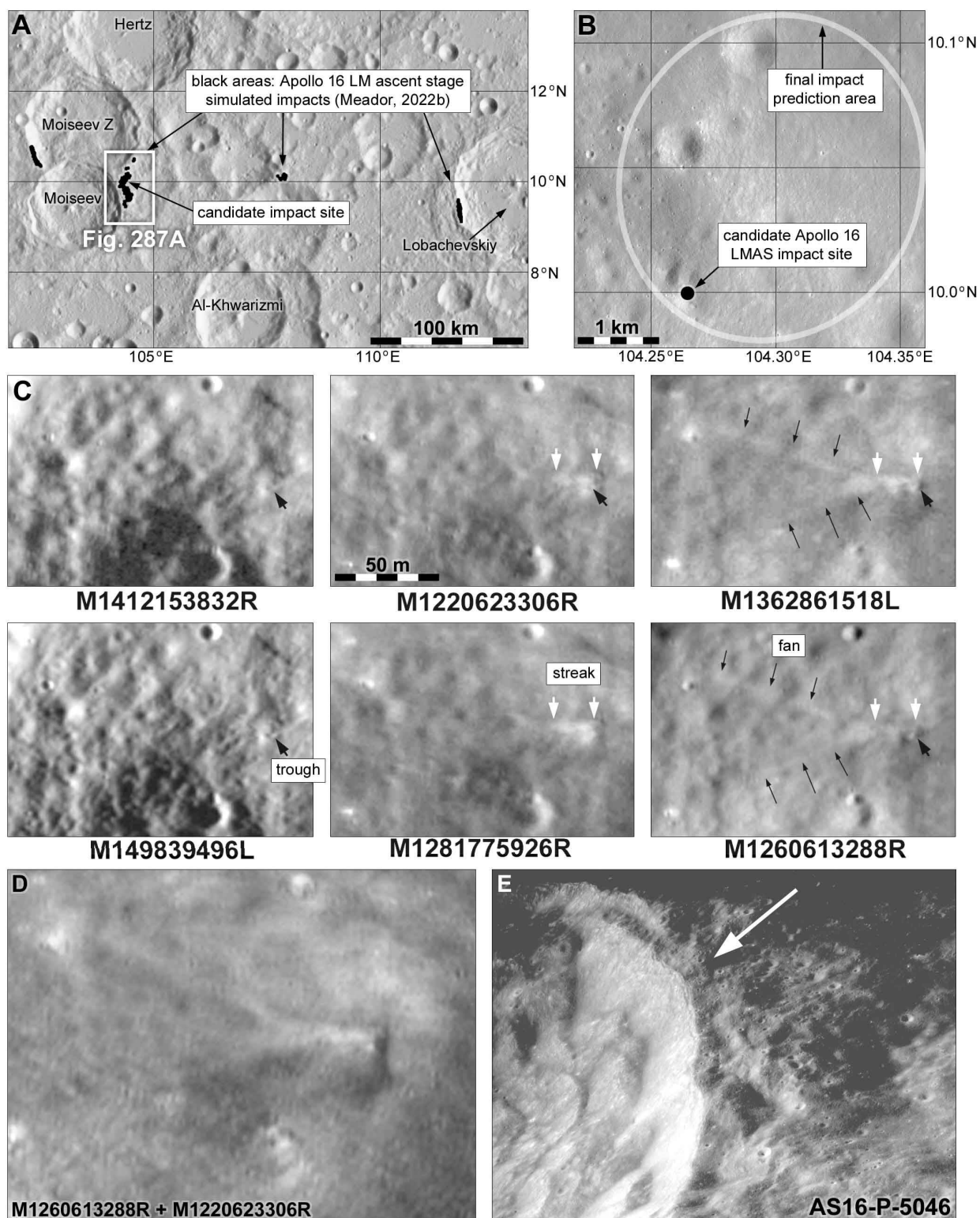


Figure 288. Apollo 16 Lunar Module Ascent Stage impact site. A, B: predicted impact sites (Meador 2022b). C: LROC NAC images with differing illumination. Impact-related features are indicated with arrows. D: images with opposite illumination merged to emphasize albedo. E: Apollo 16 panoramic camera image showing the impact area in shadow.

- Defense Mapping Agency (DMA), 1975. *Apollo 16 Traverses*. NASA Lunar Photomap 78D2S2(25), original scale 1:25000, 1st edition March 1975. <https://www.lpi.usra.edu/resources/mapcatalog/LPST/78d2s2/150dpi.jpg>
- Head, J.W., 1974. Stratigraphy of the Descartes region (Apollo 16): Implications for the origin of samples. *The Moon*, v. 11, no. 1, pp.77-99. <https://doi.org/10.1007/BF01877795>
- Meador, J., 2022a. A Reality Check. What about that Apollo 16 subsatellite? Blog post on Chasing Snoopy's Tail, 7 February 2022. <https://snoopy.rogertwank.net/2022/02/a-reality-check.html>
- Meador, J. (2022b). Impact analysis. Blog post, 14 February 2022. <https://snoopy.rogertwank.net>
- Meador, J. and Stooke, P.J., 2023. Apollo 16 lunar module ascent stage impact. Presented at the 54th Lunar and Planetary Science Conference, The Woodlands, Texas and online, 13-17 March 2023. Abstract no. 1025. <https://www.hou.usra.edu/meetings/lpsc2023/pdf/1025.pdf>
- MSC, 1972a. *Apollo 16 final lunar surface procedures*. Houston, Texas: Manned Spacecraft Center, 16 March 1972.
- MSC, 1972b. *Apollo 16 mission report*. Houston, Texas: Manned Spacecraft Center, August 1972. Report MSC-07230.
- Muehlberger, W. R. *et al.*, 1972. Preliminary geologic investigation of the landing site. *Apollo 16 Preliminary Science Report*, NASA SP-315, pp. 6-1 to 6-81. Washington, D. C.: National Aeronautics and Space Administration.
- NASA, 1972a. *Apollo 16 prelaunch mission operation report*. NASA Office of Manned Space Flight, 3 April 1972.
- NASA, 1972b. Final Apollo 16 lunar surface procedures. <https://www.nasa.gov/wp-content/uploads/static/history/alsj/a16/a16flsp.pdf>
- NASA. 1972c. *Apollo 16 Preliminary Science Report*, NASA SP-315. Washington, D. C.: National Aeronautics and Space Administration.
- Norman, M. D., Duncan, R. A. and Huard, J. J., 2010. Imbrium provenance for the Apollo 16 Descartes terrain: Argon ages and geochemistry of lunar breccias 67016 and 67455. *Geochimica et Cosmochimica Acta* v. 74, pp. 763–783. <https://doi.org/10.1016/j.gca.2009.10.024>
- Renggli, C.J. and Klemme, S., 2021. Experimental investigation of Apollo 16 “Rusty Rock” alteration by a lunar fumarolic gas. *Journal of Geophysical Research: Planets*, v. 126, no. 2, p. e2020JE006609. <https://doi.org/10.1029/2020JE006609>
- Robinson, M., 2015. Found! Apollo 16 S-IVB impact crater. Blog post, 2 December 2015. <https://www.lroc.asu.edu/posts/894>
- Sanchez, A. G., 1981. Geology of Stone Mountain, section D4 in *Geology of the Apollo 16 Area, Central Lunar Highlands*, Ulrich, G.E., Hodges, C.A. and Muehlberger, W.R. (eds), 1981. USGS Professional Paper 1048.
- Stooke, P. J., 2007. *The International Atlas of Lunar Exploration*. Cambridge: Cambridge University Press.
- Taylor, L. A., Mao, H. K. and Bell, P. M., 1973. Apollo 16 “Rusty Rock” 66095. Presented at the 4th Lunar Science Conference, Houston, Texas, 5-8 March 1973. Abstract no. 715.
- Ulrich, G.E., Hodges, C.A. and Muehlberger, W.R. (eds), 1981. *Geology of the Apollo 16 Area, Central Lunar Highlands*, USGS Professional Paper 1048.
- Young, J. W., 2012. *Forever Young: A Life of Adventure in Air and Space*. University Press of Florida.



August 1972: Solar flares

A series of solar flares between 2 and 11 August 1972 ejected charged particles and gamma rays (Chupp *et al.*, 1973; Zirin and Tanaka, 1973) which reached Earth and produced effects in communications infrastructure (Boteler and van Beek, 1999). These were among the largest solar flares ever recorded, and could have seriously harmed an Apollo crew outside Earth's magnetic field. Parsons and Townsend (2000) noted that “... the combination of high doses and high dose rates delivered to crews by solar particle events of the magnitude and duration of the August 1972 event is likely to produce significant acute effects, which could be mission- or even life-threatening unless a heavily shielded space is provided for use by the crew.” The hazard was recognized at the time and combined with

the Apollo 13 experience it contributed to a widespread feeling that Apollo had been lucky to avoid fatalities since the Apollo 1 fire.

Boteler, D.H. and van Beek, G.J., 1999. August 4, 1972 revisited: A new look at the geomagnetic disturbance that caused the L4 cable system outage. *Geophysical Research Letters*, v. 26, no. 5, pp. 577-580.

<https://doi.org/10.1029/1999GL900035>

Chupp, E., Forrest, D.J., Higbie, P.R., Suri, A.N., Tsai, C. and Dunphy, P.P., 1973. Solar gamma ray lines observed during the solar activity of August 2 to August 11, 1972. *Nature*, v. 241, no. 5388, pp. 333-335, 2 February 1973.

Zirin, H. and Tanaka, K., 1973. The flares of August 1972. *Solar Physics*, v. 32, no. 1, pp. 173-207.

Parsons, J.L. and Townsend, L.W., 2000. Interplanetary crew dose rates for the August 1972 solar particle event. *Radiation Research*, v. 153, no. 6, pp. 729-733.



Table A1. Spacecraft locations on the Moon, from this volume.

Spacecraft	Date of contact	Location	Event
Apollo 15 - SIVB upper stage - LM ascent stage - Subsatellite	30 July 1971	26.132° N, 3.633° E	Landing
	29 July 1971	1.288° S, 11.824° W	Impact
	4 August 1971	26.406° N, 0.241° E	Impact
	After January 1973	unknown	Impact
Luna 18	11 September 1971	3.57° N, 56.50° E	Impact
Luna 19	unknown	unknown	Impact
Luna 20	21 February 1972	3.787° N, 56.625° E	Landing
Apollo 16 - SIVB upper stage - LM ascent stage - Subsatellite	21 April 1972	8.973° S, 15.501° E	Landing
	19 April 1972	1.921° N, 24.623° W	Impact
	29 May 1972	9.99° N, 104.26° E	Impact
	29 May 1972	10.16° N, 111.66° E	Impact

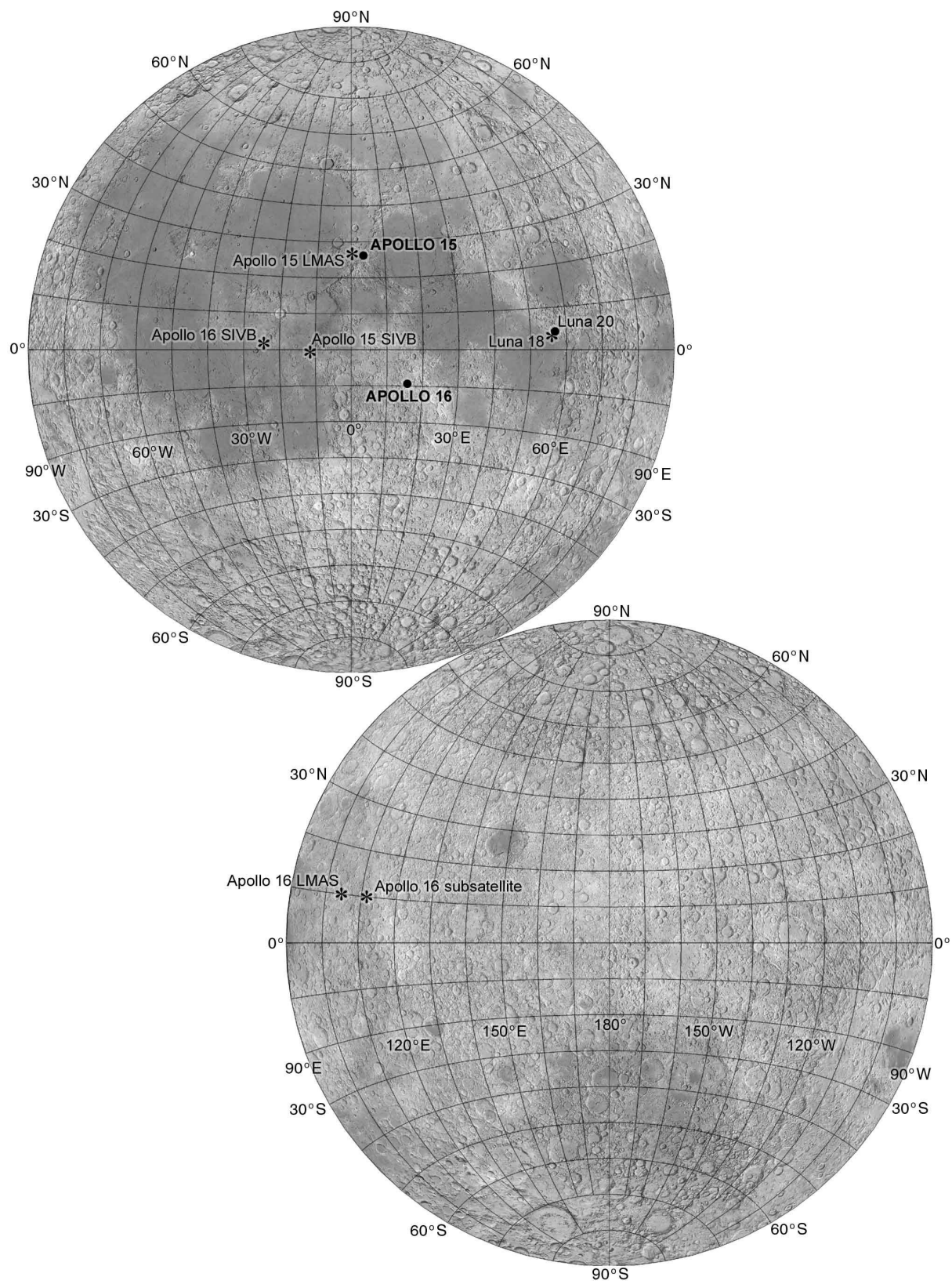


Figure A1. Lunar landings and impacts covered in this volume.